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Corn production with perennial ground covers: evaluation of cover species and their effects on corn growth and development

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Corn production with perennial ground covers: evaluation of cover species and their effects on corn growth and development

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CHAPTER 1: INTRODUCTION

The use of perennial ground covers (PGC) in corn production may offer a long term and ecological solution to soil conservation issues while allowing the removal of corn stover for biofuel production. This system has historically offered many challenges as yields have been quite variable among studies, and management practices required for PGC production systems vary from modern day practices. Issues of using perennial ground covers appear to encompass a complex genetic x environmental x management interaction that deals with availability of nutrients and light quality, as well as timing and types of management practices used with ground cover species. The overall focus of the following chapters is to elucidate certain aspects of this three-way interaction and to expand scientific knowledge of the corn and perennial ground cover production systems to expedite the development of a successful system.

Disseration Organization

The following chapters included a review of the relavent literature, a chapter on the evaluation of perennial ground covers for corn production and a chapter on the effect of low red/far-red light on growth and development of corn. Each chapter, with the exceptions of chapter 1 and chapter 6 is followed by a reference list and tables. Also, the appendix has a summary table of relavent perennial ground cover research which includes management and performance data, as well as supporting figures such as correlation matrices, anova for test of fixed effects, and calibration data for NDVI.

CHAPTER 2: LITERATURE REVIEW

Defining a Perennial Ground Cover

Throughout the literature there are many variations in the definition of "perennial ground covers" (PGC), aka "living mulches". These definitions usually vary depending on the author's opinion, field of expertise, or goals of a study. Most definitions incorporate the following phrases: "intercropped" (Zemenchik et al., 2000), "reduces soil erosion" (Hall et al., 1984), "suppress weeds" (Enache and Ilnicki, 1990), "reduces insect pests (Hartwig and Ammon, 2002)", or "supplies nitrogen" (Scott et al., 1987). These common components do not necessarily define PGC but rather the ideotype desired in the production system being discussed. If we truly want to define this term then the definition must be broad yet encompass all potential purposes of a PGC. Therefore the author will use the following definition throughout this dissertation.

> An annual or perennial plant inter-seeded with a row crop to confer an ecological, economical, or environmental benefit to the production system.

Role of Perennial Ground Covers in US Energy Goals

From 1950 to 2010 world oil demand has risen from 11 to 87.3 million barrels per day of oil equivalent (MBDOE) and is projected to be as high as 116 MBDOE by 2020 (National Research Council, 2009; IEA, 2010). In an effort to reduce US dependence on oil, reduce CO_2 emissions, and create a renewable fuel source, much attention has been given to cellulosic feedstocks as a potential fuel source. Of the 550 million dry tons of feedstock projected to be produced by 2020, corn stover (*Zea mays L.*) is expected to make up approximately 30% (National Research Council, 2009). This estimate is considered rather conservative and takes into account modern day management practices and the amount of corn residue needed sustain current production from economic, environmental, and social perspectives (National Research Council, 2009). Factors of concern when residue levels are not well maintained are: soil erosion (water and wind), nutrient cycling, and soil organic matter. Based on recommended amounts of residue that are needed to maintain these soil factors, a range of 0 – 42% of corn residue could be removed as a cellulosic feedstock using present day production practices (Wilhelm et al., 2007; NASS, 2010). These removal rates reflect the diverse range of land classes that are used in corn production, potential rotation with soybean, and take into account that certain situations will not allow for stover removal. Assuming every operation uses no-till practices, Glassner et al. (1999) estimated that 76-82% of stover could be removed. The National Research Council (2009) considered current production levels, soil conservation, various management practices in use, and the proportion of land classes involved in corn production to derive an estimate of 20.5% (75 million dry t/yr) stover removal. However, the National Research Council's report failed to correct values for moisture and inflated their estimates. Based on their calculations and reasoning, and taking into consideration their oversight on the calculations only 5% of corn stover could be removed sustainably.

Perennial ground covers grown in corn cropping systems may offer a solution to maintaining soil health while allowing for increased stover removal well above estimated levels. Perennial ground covers have been observed to reduce runoff and soil erosion on slopes as steep as 14% by 96.7 – 100%, maintain soil organic matter (SOM), immobilize unused soil nitrogen, and contribute to pest management (Hall et al., 1984; Rüttiman, 2001; Hatwig and Ammon, 2002).

Effect of Perennial Ground Covers on Environment

Soil erosion, runoff, and water infiltration

Soil erosion can be described as the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity (2007 National Resources Inventory, 2010). Perennial ground covers can provide protection to the soil by preventing these factors associated with erosion. Above ground biomass can intercept rain drops, which reduces impact, and slow wind speeds at ground level to prevent detachment, while both above and below ground structures help prevent excess soil loss by transport and redistribution forces. Hall et al. (1984) reported that crownvetch (*Coronilla varia* L.*)* and bird's-foot trefoil (*Lotus corniculatus* L) ground covers reduced soil erosion by 96.7 - 100% and runoff was reduced by 86.3 - 98% compared to conventionally tilled plots. Similar results were observed by Rüttiman (2001) on a grass-legume ground cover in corn. As an added benefit, run-off of pesticides such as cyanazine and atrazine may be reduced by 67 – 99% as well (Ruttiman, 2001; Hall et al., 1984). Perennial ground covers can also improve soil tilth, water infiltration, water holding capacity, and aeration which all contribute to the reduction of water flow on the soil surface. This is achieved through the formation of soil aggregates by increases in dead plant material, root tissues, and root exudates of PGC plus the physical forces of rooting itself (Hartwig and Ammon, 2002).

Nutrient runoff and leaching

Lack of information on nutrient runoff from crops in PGC production systems has lead to much speculation as to their effect. Much of the work that has been conducted focuses on variations in nutrient runoff between conventional tillage and no-till. When considering studies of no-till and perennial ground cover cropping systems that observe similar reduction in the rates of soil erosion (>90%), and the inherent relationship between soil erosion, and nutrient runoff, then no-till studies become reasonable models. This idea is reinforced by the observation that the percentage reduction of soil loss is proportional to the percentage reduction of total nitrogen and total phosphorus (i.e. 1-1.3) in studies comparing no-till and conventional till systems (McDowell and McGregor, 1980; Angle et al., 1983; McDowell and McGregor 1984). Much of the variability in this range could probably be attributed to crop rotation, tillage method, and the application rates of nutrients. Based on these assumptions and the observations made by Hall et al. (1984) in which soil erosion (14% slope) was reduced from 96.7 - 100 % on corn in a perennial ground cover production system, one may expect N and P losses in runoff to range from 0-26 % of that experienced in conventional tilled systems.

Reductions of nitrogen in leachate and leachate volume in subirrigated corn and Italian ryegrass (*Lolium perenne* L.) cropping systems (Kaluli et al., 1999) and rainfed alfalfa (*Medicago sativa* L.) monocultures (Rasse et al., 1999) indicate that perennial ground covers may also reduce leaching in addition to runoff in rainfed or irrigated cropping systems. Liedgens et al. (2004b) later confirmed these observations when Italian ryegrass reduced nitrogen leaching in rainfed corn from 70 mg L^{-1} to less than 10 mg L^{-1} and reduced leachate volume as much as 35 mm at a single sampling date.

Nitrogen contribution by legumes

Among species of PGC that are studied in cropping systems, legumes are the most common due to nitrogen transfer and the potential of reducing the use of inorganic fertilizers. Nitrogen transfer by legumes is primarily through root, and nodule loss, but senesced above ground tissue contributes as well (Chu and Robertson, 1974; Mallarino et al., 1990). Nitrogen transfer has been quantified with a ^{15}N isotope in several studies to try to understand legume nitrogen transfer to grasses. In most cases nitrogen transfer from legume to the grass is greatest in the absence of inorganic N with variability in the amount transferred dependent on legume species and distance to the receiving plant (Brophy et al., 1987; Mallarino and Wedin, 1990; Thorsted et al., 2006). Reed canarygrass (*Phalaris arundinacea* L.) derived a maximum of 68 and 79% of its nitrogen from alfalfa and bird's-foot trefoil, respectively, when grown in binary mixtures (Brophy et al., 1987). Mallarino et al. (1990) observed that an earlier harvest of tall fescue derived approximately 20% of total nitrogen from white clover (*Trifolium repens* L.), red clover (*Trifolium pratense* L.), and bird's-foot trefoil, but in later harvests derived as much as 60%.

Pest management

Weed suppression by PGC is usually achieved by physically obstructing or outcompeting weeds for resources via plant biomass and interception of photosynthetically active radiation (Teasdale, 1993; Teasdale and Mohler, 2000). Several studies have indicated that canopy closure in row crops is extremely influential in controlling weed emergence especially in the case of summer annual weeds with delayed emergence (Teasdale, 1995; Lindquist et al., 1998; Begna et al., 2001; Hock et al., 2006). Enache and Ilnicki (1990) observed that in a well established stand of subterranean clover (*Trifolium subterraneum* L.) in no-till corn that weed biomass was reduced 78– 90% when compared to conventional tillage + no ground cover. Subterranean clover in no-till corn also increased weed control (population reduction) over the conventional tillage + no ground cover for ivyleaf morning-glory (*Ipomoea hederacea* Jacq.) and fall panicum (*Panicum dichotomiflorum* Michx.) by as much as 62 and 18%, respectively. Several studies indicate that similar success can be achieved with red clover and hairy vetch (*Vicia villosa* Roth.) (Palada et al., 1982; Hoffman et al., 1993), however, Zemenchik et al. (2000) observed much poorer weed suppression with kura clover (*Trifolium ambiguum* M. Bieb.) and speculated that monocultures of kura may not be as effective in weed control. Given that many of the PGC studied are C3 species, their early development could have profound effects on weed populations, weed biomass, and soil weed seed banks. Alleopathic effects specifically have not been quantified in weed suppression in row crops but several species such as tall fescue (*Schedonorus phoenix* (Scop.) Holub.), perennial ryegrass, and subterranean clover produce alleochemicals that have been shown to contribute to suppression of other species (Peters and Mohammed Zam, 1980; Sutherland and Hume, 1999; Hartwig and Ammon, 2002).

Perennial ground covers may confer insect suppression to row crops by harboring natural insect predators such as ground-dwelling beetles (Prasifka et al., 2006; Schmidt et al., 2007) and spiders (Hooks and Johnson, 2004). Studies with alfalfa and kura clover as PGC in corn and soybean (*Glycine max* (L.) Merr.) have indicated that predator abundance and predation of damaging insects such as the soybean aphid (*Aphis glycines)* and European corn borer (*Ostrinia nubilalis*) can be significantly increased over traditional cropping systems

(Prasifka et al., 2006; Schmidt et al., 2007). Schmidt et al. (2007) concluded that the presence of alfalfa in soybean plots increased predator abundance by 45% and significantly contributed to predation of the soybean aphid. Similar conclusions by Prasifka et al. (2006) for soybean aphid and European corn borer help confirm this increase in predator abundance, but the results also indicate that an interaction between the crop and ground cover facilitates this abundance as alfalfa and kura clover alone harbored significantly less predators.

Perennial Ground Covers in Corn Production Systems

Corn yields

Corn grain and total biomass yield can be devastated by unsuppressed ground covers regardless of species. Corn grain yields in unsuppressed covers have been reported to be reduced by 63 – 99% for alfalfa (Elkins et al., 1983; Eberlein et al., 1992), 48 – 100%, 48%, and 74% for smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and tall fescue, respectively (Elkins et a., 1983). Few successful examples of non-suppressed ground covers have been reported, but studies that have produced grain yields equal to those of conventional management methods have involved legumes seeded several weeks after corn emergence (Scott et al., 1987; Abdin et al., 2000) and self seeded subterranean clover (Enache and Ilnicki, 1990). The sensitivity of corn to living ground covers in early stages of development will be discussed in a later section concerning the critical period of weed control.

Annually seeding ground covers into standing corn may be difficult, costly, and time consuming to producers, therefore researchers have strived to develop systems which suppress ground covers in early spring to reduce competition and increase grain yields.

Several methods of suppression may be involved but the most common methods or combination of methods involves broadcast herbicide suppression, band suppression, physical mowing, strip-tillage, or minimum-tillage such as discing (Adams et al., 1970; Elkins 1983; Enache and Ilnicki, 1990; Zemenchik et al., 2000). Results from studies that use individual or combinations of these suppression methods are quite variable and appear to be dependent on numerous factors that involve the timing of the suppression, species being suppressed, the severity of the suppression (chemical rate), geographic location of the study, N fertilization, and climatic factors such as temperature and water availability. Corn genetics is another factor that can be considered yet is difficult to quantify among research studies. Variations in growth and development between old and new varieties and among varieties released within a similar time period have been directly related to the plant's tolerance to inter- and intra-specific competition (Maddonni et al., 2002; Tollenaar et al., 1997; Tollenaar et al., 1992).

Chemical suppression methods are broadcasted or band applied and incorporate a wide range of chemicals, rates, and in the case of bands the width of application (0.15 – 0.61 m) (Appendix I). Banding is usually conducted to kill the ground cover within the crop row while broadcast herbicide treatments kill or only suppress growth for a short period of time. Combinations and individual usage of these methods have been successful in a variety of PGC production systems and have resulted in grain yields meeting or exceeding production goals (Appendix I). In some cases strip-tillage may be as effective as band herbicide application, but may still require some form of weed control to be comparable to conventional tillage systems (Adams et al., 1970; Zemenchik et al., 2000).

Corn yields in suppressed ground covers are directly related to the amount of viable ground cover retained after the suppression, with less ground cover resulting in higher yields. Elkins et al. (1979 and 1983) observed this relationship between corn grain yields and percentage of ground cover in various species. The authors concluded that good corn yields could be obtained as long as ground cover was maintained below 50-60%. Kumwenda et al. (1993) varied the widths of banded herbicide from 0 to 100% over the corn row and concluded that 20 – 40% of crimson clover (*Trifolium incarnatum* L.) could remain without suppressing corn yield.

Water, nitrogen, and light interception are many times given credit for reducing corn grain yields when interseeded with ground covers and without doubt influence soil water and nutrient dynamics (Rajcan and Swanton, 2001). However many of the studies previously discussed still indicate yields are significantly less in the presence of ample light, water, and nutrients unless ground covers are immediately suppressed or killed. Early season corn growth in PGC also confirms this as plant stress is many times evident shortly after corn emergence when resources (light, water, nutrients) are ample (Page et al., 2009).

Yield components and plant growth

Perennial ground covers may affect corn grain yield in a variety of ways. One of the most notable ways by which this occurs is through reduction in plant population. Regardless of whether the ground covers are broadcast, band, or stip-tillage suppressed significant reduction in population may occur. Zemenchik et al. (2000) observed a 12% and 28% reduction in corn population for band-killed and suppressed kura clover, respectively. They attribute this to cool spring conditions that suppressed corn growth but allowed kura clover to regain its competitiveness earlier in corn development. Enache and Ilnicki (1990) reported a 13% reduction in corn population in subterranean clover during the third year of their study which they attributed to poor corn germination in early spring. The authors also observed reduced corn populations of up to 20% in subterranean clover and dead rye mulch (*Secale cereal* L.) ground covers during the first year but failed to speculate the cause. However, the authors did report that cover treatments during the first year of the study were ineffective in controlling fall panicum (*Panicum dichotomiflorum* Michx.) which may be responsible for the population reduction.

Harvest index in corn is relatively stable under conventional management and perennial ground cover systems (Adams et al., 1970; Duvick 1984; Martin et al. 1999). The stability of the harvest index may indicate that corn grain production, at least in suppressed PGC, is largely determined by population and plant vigor, and much less dependent on kernel number and size (Abdin et al., 1998). This is rather surprising considering that suppressed PGC have delayed corn tasseling by as much as 20 days (Adams et al., 1970). However, when ground covers are extremely competitive, harvest index may drop as well. Eberlein et al. (1992) observed disproportional grain and stover yields in unsuppressed, rainfed alfalfa that resulted in HI being reduced 61 - 89%.

Ecological, Environmental, and Management Factors

Corn planting dates and time of cover suppression

Planting dates and cover suppression dates are critical in determining the degree of success of corn grown with PGC. Perennial ground covers are often C3 species and have higher photosynthetic rates under cool conditions compared with C4 species (Taiz and

Zeiger, 2002). Thus planting early or suppressing just prior to planting appears to be more successful than delaying. Another factor to consider is that spring climate in the Central US is very unpredictable in terms of temperature and frost events. Given the role of soil thermal emittance in controlling air and leaf temperatures (Monteith and Unsworth, 2008) and the reduction in soil temperatures usually recorded under living ground covers, corn may be more susceptible to frost damage in PGC systems (Martin et al., 1999).

Competition for soil moisture

Moisture stress is many times reported as the main factor in suppressing corn yield in PGC systems (Eberlein et al., 1992; Kumwenda et al., 1993). However, several weed studies have indicated that soil moisture under weedy conditions are unaffected or are actually higher than bare soil treatments (Young et al., 1984; Tollenaar et al., 1997; Thomas and Allison, 1975). Martin et al. (1999) reported that corn grown in a white clover x grass mix consistently had higher soil water content regardless of water stress. The authors observed that soil water content, after a brief dry period, dropped to 5% in the upper soil surface (0 – 0.15 m) for the control yet never went below 20% in perennial ground cover plots. Corn grain yields were still reduced by 23 – 77% across all cover treatments. Zemenchik et al. (2000) concluded that soil water was not a factor in determining corn yield in their study as no significant difference in soil moisture was observed among corn in kura clover treatments.

Competition for soil nitrogen

Competition for soil nitrogen is an obvious issue with corn grown in PGC systems. The presence of PGC in corn has been shown to reduce soil NO^{-3} levels by as much as 90% when compared to bare soil treatments (Liedgen et al., 2004b) and has been shown to significantly reduce corn grain and stover N yields (Zemenchik et al., 2000; Liedgen et al., 2004b). This would explain the interest most researchers have in developing legume PGC. In a five-year study, Scott et al. (1997) compared conventional tilled corn at various nitrogen rates with corn planted in monocultures of medium and mammoth red clover, alfalfa, yellow sweetclover (*Melilotus officinalis* (L.) Lam.), bird's-foot trefoil, hairy vetch, white clover, and annual ryegrass, (*Lolium multiflorum* Lam.), and a binary mixture of annual ryegrass x medium red clover. During the first year the authors observed similar corn grain yields between late seeded legume plots (seeded at corn height of 0.15 – 0.30 m) and conventional tilled plots that were fertilized with 0 – 95 kg ha^{-1} N. Subsequent years produced varied results in which higher nitrogen rates (95 kg ha^{-1}, conventional tillage) sometimes produced corn yields that exceeded those in legumes plots. Legumes as ground covers may be insufficient in supplying N for high yielding corn production systems without supplementing soil nutrients (Sawyer et al., 2010) as they appear to supply far less N as compared to that recommended for corn production.

Despite the potential contribution of legumes, little to no benefit is realized as evidence suggests inorganic nitrogen requirements remain equal to conventional cropping methods (Sawyer et al., 2010) and yields are still significantly reduced unless legumes are killed or suppressed (Eberlein et al., 1992; Kumwenda et al., 1993; Zemenchik et al., 2000). This is likely the result of inorganic N suppressing dinitrogen fixation. When inorganic N is applied legumes become more dependent on soil N and fix less atmospheric nitrogen, thus no longer needing the costly symbiosis with rhizobia (Streeter, 1988; Parsons et al., 1993). When comparing treatments of 0 and 100 kg ha^{-1} nitrogen, Mallarino and Wedin (1990) observed significant reductions in atmospheric derived nitrogen in white clover, red clover and bird's-foot trefoil during early season harvests yet insignificant changes in later (18 – 20 weeks) harvests. They concluded from these findings that the inhibition of nitrogen fixation was relieved once soil nitrogen levels were diminished below some physiological threshold. Thus the application of inorganic N to supplement fixed N could result in depletion of soil N earlier in corn growth than normal.

Critical period of weed control

Growing a perennial ground cover with row crops is basically an attempt to select and manage a weedy species while maintaining an acceptable level of production. When one considers the plethora of research dedicated to the effects of weed pressure on crop yields and the emphasis placed on weed control, the previous statement appears to be a paradox. For this reason the weed science literature becomes key in trying to understand many of the issues with growing corn in PGC systems. Of particular interest is the research focused on the "critical period of weed control" (CPWC) as it attempts to outline the timing and duration of acceptable weed pressure. In practice, the CPWC is defined as the time period after emergence in which weeds must be controlled in order to maintain 95% of the achievable yield (Rajcan and Swanton 2001). Reports from studies in Canada are conflicting indicating that the beginning of the CPWC varies between V3 to V14 yet has a stable end period at approximately V14 (Hall et al., 1992). Other studies report that the beginning is relatively stable at V6 with a more variable ending point (Hartford et al., 2001). Studies within the Midwest US observed the beginning of the CPWC as quickly as VE and ending sometime between V5 to VT (Evans et al. 2003). Most of the disagreement between studies such as these has been largely attributed to differences amoung weed species, density, and timing of emergence (Weaver et al., 1992; Norsworthy and Oliveira, 2004). Other factors that shouldn't be ignored and appear to be significant from these studies are location, climate, and nutrient availability (Hall et al., 1992; Evans et al., 2003).

Most studies that focus on timing of weed pressure in corn seem to agree that early weed pressure is more detrimental to corn yield than weed pressure later in development (Dew 1972; O'Donovan et al., 1985; Knezevic et al., 1994; Bosnic and Swanton, 1997). Perennial ground cover studies support these observations with establishment of ground cover species several weeks after corn emergence having little effect on grain yield (Scott et al., 1987; Abdin et al., 2000). Bosnic and Swanton et al. (1997) observed 26 to 35% reduction in corn grain yield with early emerging (V1-V2) barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) yet only a 6% yield loss on an equal density stand emerging after V4. Weed threshold studies have also determined the effect of varying weed populations on corn grain yield. Studies on johnsongrass (*Sorghum halepense* (L.) Pers.) (Ghosheh et al., 1996) redroot pigweed (*Amaranthus retroflexus* L.) (Knezevic et al., 1994), quackgrass (*Elymus repens* (L.) Gould) (Young et al., 1984), and barnyardgrass (Bosnic and Swanton, 1997) have observed yield losses of up to 47% as weed populations have increased. Results such as these give an indication as to why researchers have observed higher grain yields in corn in perennial ground cover production systems when early chemical suppression was involved (Martin et al., 1999; Zemenchik et al., 2000; Liedgen et al., 2004a).

Detection of light quality and quantity

A unique characteristic among higher plants is their ability to alter their physiological and morphological development to accommodate their environment. In no instance is this more prominent than when plants are exposed to variations in light quality and quantity incident on the developing canopy. The red/far-red ratio (r/fr), a key signal for plants in determining light quality, can act as an early signal of potential competition and resource limitation so that plants may alter their growth and development (shade avoidance syndrome) for improved fitness (Ballare et al., 1987; Ballare et al., 1990; Franklin and Whitelam, 2005).

Although phytochrome wasn't discovered until 1959 (Butler et al. 1959), its effects had been studied since the 1930's on seed germination response to red light (Flint et al. 1936; Borthwick et al. 1952). Since that time numerous experiments have been conducted not only on seed germination but also the r/fr effect on plant development. These effects and others have been documented in a variety of species such as European white birch (*Betula pendula* Roth) (Aphalo and Lehto, 2001), Chinese thorn-apple (*Datura quercifolia* Kunth.) and white mustard (*Sinapis alba* L.) (Ballaré et al., 1990), Chrysanthemum (*Chrysanthemum ×morifolium* Ramat. pro sp.) (Khattak et al., 2004), soybean (Kasperbauer et al., 1984; and Kasperbauer, 1987), Cotton (*Gossypium hirsutum* L.) (Kasperbauer and Hunt, 1992), barnyardgrass (Maliakal, 1999), Tobacco (*Nicotiana tabacum L.)* (Kasperbauer and Peaslee, 1973), white clover (Heraut-Bron et al., 1999), and corn (Kasperbauer and Karlen, 1994; Rajcan et al. 2004; Liu et al., 2009).

Phytochrome, an apoprotein belonging to a closely related family of photoreceptors, is the primary receptor given credit for receiving the r/fr signal and initiating the biochemical response responsible for physiological and morphological changes that occur during shade avoidance (Taiz and Zeiger, 2002). This multigene family is responsible for signaling biological processes ranging from changes like those previously discussed to circadian rhythms (Jarillo et al., 2001). Angiosperms are typically observed to have three dominant forms of phytochrome (PHYA, PHYB, and PHYC) with dicots exhibiting an additional two forms (PHYD and PHYE) (Franklin and Whitelam, 2005). For the purpose of the following chapters, PHYA and PHYB are the most likely forms of interest as they have been identified as the major contributors in controlling shade avoidance syndrome (Somers et al., 1991; Devlin et al., 1992).

Phytochrome can assume two different forms: Pr (red light absorbing form) and Pfr (far-red light absorbing form). Pfr is considered the physiologically active form and is favored by high r/fr incident on the canopy, as would be incurred in full sunlight. Thus plants receiving high r/fr signals can be characterized as having high proportions of Pfr relative to Pr. In a sun tolerant plant this would result in "normal" growth and development. Assuming a sun tolerant plant were shaded by a dense canopy or receive a significantly lower r/fr signal from neighboring vegetation, one would observe a lower proportion of Pfr relative to Pr and see characteristics of shade avoidance (Taiz and Zeiger, 2002). For an in-depth discussion on phytochrome in cell biology see Møller et al. (2002).

The basic mechanism by which changes in r/fr occur in a canopy is directly related to the absorption, transmittance, and reflectance of lateral, underlying, and overshadowing objects such as soil, plant residues, and adjacent vegetation. Healthy leaves may absorb and reflect approximately 90% and 5%, respectively, in the red band (655 – 665nm) and absorb and reflect approximately 25% and 50%, respectively, in the far-red band (725-735nm) (Monteith and Unsworth, 2005). To put these values in perspective, irradiance (watt/m^{-2}) on a clear summer day may give rise to r/fr ratios incident on the canopy of approximately 1.1 – 1.2 with variability resulting from the day-of-year (DOY) and time of day when measured.

Reflectance of these two bands from bare soil may be more variable depending on water content, angle of incidence, particle size, and mineral and organic properties of the soil (Monteith and Unsworth, 2005). Soil r/fr values can typically range from approximately 0.7 to 1.2, with wetter and higher organic soils representing the upper limit (Monteith and Unsworth, 2005). When the soil is covered with dense vegetation (> 95% light interception) the reflected r/fr ratio from canopy may be as little as 0.05 depending on the health of the vegetative cover (Smith, 1982). Light transmitted through a dense canopy to vegetation below (shading) may exhibit similar values of those reflected from the dense canopy assuming:

$$\rho(\lambda) \sim \tau(\lambda)$$

(Monteith and Unsworth, 2005)

where ρ = reflectance, τ = transmittance, and λ = wavelength. Given these observations and assumptions it is apparent that deviations in the r/fr, in relation to that observed in direct sunlight, can be greatly influenced by not only shading but by reflected light from neighboring plants and underlying surfaces.

Plant responses to red/far-red signaling

Changes in plant physiology and morphology in response to light quality and quantity are numerous yet are normally characterized by main axis elongation, longer yet narrower and thinner leaves, increased leaf area index early in development, and changes in photoassimilate partitioning (Kasperbauer and Peaslee, 1973; Kasperbauer and Hunt; 1992; Heraut-Bron et al., 1999; Rajcan et al., 2004). Unfortunately these effects of low r/fr signals on growth and development are not always conducive to row crop production systems. For instance the shade avoidance strategy exhibited by corn may negatively affect grain yield as it has been linked to reducing instead of increasing reproductive fitness (Rajcan et al., 2004; Page et al., 2009; Page et al., 2010). Maddonni et al. (2002), after observing changes in development of different corn cultivars to low r/fr signals, speculated that response-specific genes operating downstream from phytochrome provided a selective strategy for eliminating competition yet it comes at the expense of grain yield. Liu et al. (2009) concluded that detection of early weed pressure by corn seedlings reduced reproductive fitness and the plant's ability to respond to abiotic stress later in development.

Numerous studies in corn have indicated that low r/fr signals primarily alter the partitioning of photoassimilates to above ground structures. Kasperbauer and Karlen (1994) observed that changes in r/fr from 1.00 to 0.85, from the reflected soil surface, could significantly alter the shoot/root (weight ratio) from 0.88 to 1.21 in corn seedlings. Similar changes have been observed in cotton seedlings with shoot/root ratios of 0.95 and 1.27 for low and high r/fr ratios respectively (Kasperbauer and Hunt, 1992). A more recent study by Page et al. (2009) indicated that this change in shoot/root ratio may occur early in corn seedling development. Treatments receiving low r/fr treatments (0.60 ratio) three days after emergence exhibited significant increases in shoot/root ratios whereas seedlings that received the same treatment later in development (6 -15 days after emergence) were not affected. This higher shoot/root ratio may only be temporary. Liu et al. (2009) subjected corn seedlings to low and high r/fr ratios and harvested plant biomass at leaf tip stages 4, 6, 9, 11, and 15. Root dry matter in low r/fr treatments was significantly less than the high r/fr ratio control for each sampling stage. Between the 9^{th} and 11^{th} leaf tip stages corn plants in the low r/fr treatments were observed to be significantly shorter with less shoot dry matter and significantly lower LAI's. As a result, shoot/root ratios of seedlings started out significantly higher in the beginning but by the 9th leaf tip stage they were no different from the control. Based on these results it is unlikely that roots are experiencing compensatory gain. It is more likely that a decrease in plant growth and development of above ground tissues allows root biomass to regain its normal relative proportion to the above ground biomass. The more important message from these studies is that root growth is inhibited early in plant development so that more photoassimilate can be partitioned to above ground structures to increase the plant's ability to compete. Some plants, such as in the case of corn, are unable to regain this root mass resulting in decreased acquisition of below ground resources.

Changes in canopy architecture and factors associated with leaf photosynthesis can also be induced by changes in r/fr ratios. Maddonni et al. (2002) observed significant changes in leaf orientation from a parallel to perpendicular row position in transplanted corn seedlings from a commercial variety. Rajcan et al. (2004) made a similar observation in a growth chamber study in which a low inter-row r/fr signal (grass sod) was used to change leaf orientation from perpendicular to a more favorable parallel position. Other changes that are likely to occur in corn but have only been studied in other species include fewer stomata per unit leaf area, fewer and smaller starch grains, thinner leaves (increased transmittance), and reductions in leaf chlorophyll content (Kasperbauer and Peaslee, 1973; Kasperbauer and Hunt, 1992; Heraut-Bron et al., 1999). However, it should be noted that when stomatal number and chlorophyll content are expressed on a no./fresh wt basis that low r/fr treated plants were not different from normal growing plants. This may help to explain why some studies have found no significant difference or an increase in net CO_2 uptake in plants receiving low r/fr light (Kasperbauer and Peaslee, 1973; Holmgren, 1968; Hesketh and Moss, 1963).

Summary

Growing corn in PGC is a complex problem that encompasses competition for resources, non-reversible physiological and morphological changes, light quality issues, timing issues, and possible changes to the microenvironment (i.e. soil temp) that require intensive management to overcome. Therefore, it is necessary to identify what species are best suited for perennial ground cover systems and to identify ideotypes so that future screening of species can be more focused.

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CHAPTER 3: EVALUATION OF GRASS AND LEGUME SPECIES AS PERENNIAL GROUND COVERS IN CORN PRODUCTION

A paper to be submitted to Crop Science

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Abstract

Corn stover has been identified as an important feedstock for future biofuel production but increased soil erosion will make its removal difficult. To address this issue 35 species of grasses and legumes were evaluated as potential perennial ground covers in corn. Selection of species encompassed both C3 and C4 species with a wide range of developmental and morphological features such as height, vegetative spread rate, and sod and clump forming growth habits. The objectives were to: (i) identify species that could support a high level of corn production while requiring minimal management, and (ii) to identify a potential ideotype for future selections. Species that were low growing and slow spreading were more conducive to corn production but still reduced yields a minimum of 23% when compared to a conventionally managed control. Conditions that slowed corn growth in early development such as cool temperatures, and frost allowed C3 species to gain a competitive advantage. Strip tillage was difficult during initial corn establishment and indicates the need for strip-planting of cover. Species that consistently worked well with corn were meadow fescue, sheep fescue, Canada bluegrass, fowl bluegrass, and colonial bentgrass. These species also offer the most flexibility during spring as they are less aggressive than other species evaluated. Based on these observations an ideotype should be low growing, slow spreading, and late to green-up in the early spring.

Introduction

Estimates of world oil demand are projected to be as high as 116 million barrels per day of oil equivalent (MBDOE) by 2020 (National Research Council, 2009: IEA, 2010). This is nearly a 33% increase in relation to the demand experienced at the completion this study. To reduce dependence on oil, from both foreign and domestic sources, much attention has been given to cellulosic material as a feedstock for biofuel production. Estimates by the National Research Council (2009) project that 50 million Mg of dry material could be available by 2020, of which corn stover could make up as much as much as 30%. This estimate of stover availability only assumes a fraction of the material can actually be removed because stover residue is an integral part of soil conservation. Considering the variability among production practices and topographical features used in corn production at present day, estimates of 0-42% removal could be achieved depending on methods and location of production (Wilhelm et al., 2007; NASS, 2010). Other estimates indicate that 76 – 82% removal is possible if all production involved no-till practices (Glassner et al., 1999). A potential solution that would allow for increased stover removal while preventing soil degradation is the use of perennial ground covers (PGC), sometimes referred to as living mulches. Perennial ground covers can be defined as an annual or perennial plant that is interseeded with a row crop to confer an ecological, economical, or environmental benefit to the production system. Annuals are included in this definition as reseeding may allow covers to reestablish in years following initial seeding.

Perennial ground covers have multiple benefits which they may confer to row crop systems. These benefits include: reduced soil erosion (96.7 -100%) and surface runoff (86.3 -98%) (Hall et al., 1984); reduced run-off of pesticides such as cyanazine and atrazine (67-

99%) (Ruttiman, 2001; Hall et al., 1984); reductions in leached nitrogen (N) (86%) (Liedgens et al., 2004b); N immobilization (Fageria et al., 2005); increased populations of predatory insects (Prasifka et al., 2006; Schmidt et al., 2007); and weed reductions (Enache an Ilnicki, 1990). Sometimes authors also include nitrogen contributions as a benefit when legumes are used as PGC but little evidence supports that desired levels of corn production can be achieved by N supplied by legumes (Sawyer et al., 2010; Zemenchik et al., 2000). Regardless, the soil protection aspect alone warrants the use of PGC in corn production.

Perennial ground covers have historically been associated with significant reductions in corn grain yields with unsuppressed ground covers generally performing the worst. Significant yield reductions ranging from 48 – 100% have been observed in species such as alfalfa (*Medicago sativa* L.), smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and tall fescue (*Schedonorus phoenix* (Scop.) Holub) under no-till conditions (Elkins et al., 1983; Eberlain et al., 1992). Reductions in corn grain yields when grown with PGC are sometimes linked to reductions in yield components such as population and harvest index. Populations have been reported to be reduced by 12 – 28% for kura (*Trifolium ambiguum* M. Bieb.) and subterranean clovers (*Trifolium subterraneum* L.), while harvest index has been reported to be reduced 61- 89% in rainfed, no-tilled corn in alfalfa (Zemenchik et al., 2000; Eberlain et al., 1992). According to Zemenchik et al. (2000) cooler spring conditions may have played a role in the reduction of the corn population in kura clover treatments through reduced germination. This is likely a good explanation as vegetative cover can affect soil temperatures (Monteith and Unsworth, 2005) and thus germination. But another factor to consider is the reduction in thermal emmitance that accompanies reduced soil temperatures and the effect that it has on leaf temperatures. This can certainly make corn seedlings susceptible to frost and has in fact been cited as an issue with PGC based on observations by Martin et al. (1990). But the last and possibly the most important factor to consider is that cooler spring conditions will favor the growth of C3 species over C4 species and thus leave corn at a disadvantage early in the season in the absence of management.

Improvements in corn grain yield over no-till systems can be achieved with chemical and mechanical suppression of ground covers but results among studies are extremely variable as species, location, and management appear to interact. However, most studies that have evaluated rates of chemical suppression and tillage methods have observed production practices that would allow high levels of corn production. For instance, Hall et al. (1984) observed no difference between a conventionally tilled control and bird's-foot trefoil when suppressed with paraquat and cyanazine at rates of 2.2 and 4.5 kg ai/ha, respectively. Elkin et al. (1983) has observed similar success in tall fescue, orchardgrass, smooth brome, and alfalfa but rates and chemicals involved with each species success sometimes varied. Combinations of chemicals and timing of application all play a role in determining the success of these systems but it appears that most species can be controlled well enough to achieve yields comparable to conventionally tilled methods. Strip-tillage is rarely used without chemical suppression but does appear to improve performance when used (Martin et al., 1999; Adams et al., 1970).

Resource availability undoubtedly plays a role in reducing grain yields when corn is grown with a perennial ground cover. However, many times corn seedlings appear stressed in the presence of ground covers or weed species early in the season when most resources are ample (Page et al., 2009). This observation has led to the hypothesis that shade avoidance, which may be caused by either shading or by the low red/far-red (r/fr) reflected light, can play a significant role in yield reductions through phenotypic constraints (ie changes in early plant development that reduce growth and reproductive fitness) (Rajcan et al., 2004). Another factor to consider is the critical period of weed control for corn (CPWC) which is defined as the time period after emergence in which weeds must be controlled in order to maintain 95% of the achievable yield (Rajcan and Swanton 2001). The CPWC may begin as early as VE and ends sometime between V5 and VT (Evans et al., 2003). Many ground cover species will likely overlap with most if not all this time period. These factors may help to explain why suppression is so critical to the success of corn grown in PGC. Given the variability in growth and development among grasses and legumes this may also help to explain why so much variability in grain yields is observed among ground cover species.

Spring conditions are difficult to predict in the Midwest, resulting in variable temperatures, rainfall, and planting dates. Grasses and legumes have to provide some level of flexibility in their growth and development, as well as be persistent in order to be feasible candidates for PGC in this region. This is especially important when one considers the lag time that may take place between suppression and corn planting or conditions that may temporarily suppress corn growth and development. These factors in turn decrease the time corn will go without competition during the CPWC. A wide range of growth habits are available among grasses and legumes, sometimes even within a particular genus. Most PGC tested to date are the result of qualities believed to be important in minimizing competition with corn while achieving some ecological economical or environmental benefit. Little has been done to test the suitability of ground covers themselves in terms of their competitiveness, persistence, cover provided, and leniency in timing of management.

Therefore the objectives of this study are to (i) identify species that could support a high level of corn production while requiring minimal management, and (ii) to identify a potential ideotype for future selections.

Materials and Methods

Field experiments were conducted at the Sorensen Research Station in Boone, IA (42°00’N, 93°44’W, 330 m above sea level) from 2008 to 2010. Plot soils consisted of predominately Clarion and Webster soils (0 – 5% slope, fine-loamy, mixed superactive, mesic Typic Endoaquolls) with Nicollet soils (0-3% slope, fine-loamy, mixed, superactive, mesic Aquic Hapludolls) and Canisteo soils (0-2% slope, fine-loamy, mixed, calcareous, mesic Typic Endoaquolls) making up a lesser portion (<5%). The field experiment was arranged as a split-block in time and consisted of three 1.4-ha blocks split into three landscape positions: summit (0-2%), slope (2-5%), and toeslope (0-2%). Thirty-five ground cover treatments (Table 1) and one bare soil control (sub plots) were established perpendicular to the slope in 3-m wide strips from the toeslope to summit for a total of 108 treatments replicated three times over three years. Perennial ground cover species were established in the spring of 2006 on tilled soil with a 2.1-m Tye 104-4404 Pasture Pleaser no-till seeder (AGCO Corporation, Duluth, GA) at 7.4 million pure live seed per hectare (approx. 1.5 times the recommended rate for most species). Plots that did not establish well were tilled and re-seeded or over-seeded on 15 May and 4 June 2007 (Table 1). Plots that failed to establish during the May and June seeding were tilled and reseeded again on 15 August 2007 with a Brillion SSP-5 seeder (Brillion Farm Equipment, Brillion, WI) to ensure good seed-to-soil contact, as this was believed to be the primary cause of poor establishment.

To establish corn in perennial ground cover plots, strip-tillage was used to create a cover free zone for planting. Rows were established parallel to the slope, thus perpendicular to previously establish groundcover treatments to create 36, 3.0 m x 23.0 m plots at each of the three landscape positions. Unfavorable weather conditions in the fall of 2007 and 2008 delayed strip-tillage until the following springs, but strips were tilled in the fall of 2009 for the 2010 growing season. Strip-tillage was accomplished using a four-row Unverferth Ripper-Stripper (Unverferth Mfg. Co., Kalida, OH) on May 7, 2008, May 4, 2009, and for establishment of the 2010 crop tillage was conducted November 16, 2009. The Ripper-Stripper was customized with a single 0.44 m diameter, 0.025 m fluted, 13-waved coulter in front, followed by an adjustable deep-till shank that penetrated the soil to a depth of 0.25 m. Two sets of dual, offset coulters (identical to the front coulter) were mounted directly behind the shank and were adjusted in angle and width to accommodate a 0.30 m tillage width. A 0.38 m wide Rolling Harrow®, 0.30 in diameter, was attached behind the coulter to level and chop the seed bed. In 2008 and 2009, conventional tillage methods were used in the control plots but in 2010 only spring strip-tillage was conducted. Glyphosate [N-(phosphonomethyl) glycine], centered 0.30 m over the corn row, was applied at 3.0 kg ai ha^{-1} between corn growth stages V2 - V4 in an effort to suppress summer annual weeds. In 2010 additional grass and broadleaf control was banded with a tank mix of acetochlor [2-chloro-2'-methyl-6'-ethyl-N-ethoxymethylacetanilide], flumetsulam [N-(2,6-difluoropheny)-5-methyl-1,2,4-triazolo-[1,5a]- pyrimidine-2-sulfonamide], and clopyralid potassium salt [2,6-dichloro-anpyridinecarboxylic acid, potassium salt] at rates of 1.8 kg ai ha^{-1}, 0.05 kg ai ha^{-1}, and 0.14 kg ai ha^{-1}, respectively.

Field corn hybrid “Pioneer 34A20” was planted in 0.76 m row spacings on 19 May 2008, 14 May 2009, and April 21, 2010 with a four-row Kinze 3000 pull type planter (Kinze Mfg, Iowa City, Iowa). Populations in 2008 and 2009 were set at 80,000 seeds ha^{-1}, but calibration issues resulted in a population of 74,000 in 2010. Planting dates for 2008 and 2009 were later than recommended for Iowa (20 April – 5 May [Elmore and Abendroth, 2001]) but rainfall events prevented earlier planting. Urea ($CO(NH_2)_2$) was applied at the equivalent of 168 kg ha^{-1} N in all three years of the study. Phosphorus (P) and potassium (K), in the forms P_2O_5 and K_2O, respectively, were applied based on yearly fall soil tests and soil fertility recommendations by Iowa State University Extension (Sawyer et al., 2002). To achieve “high” yearly levels of soil P and K the following rates were applied: 11 kg ha^{-1} P and 151 kg ha^{-1} K, 2008; 60 kg ha^{-1} P and 134 kg ha^{-1} K, 2009; and 50 kg ha^{-1} P and 134 kg ha^{-1} K, 2010. All soil amendments were band applied over the corn row at planting with a Gandy Model 62 Series air-delivery fertilizer system (Gandy Company, Owatonna, MN). Soil pH ranged from 5.8 to 6.9.

Data collection

Spring ground cover was determined at corn growth stage V4 in 2008 and 2009 and at V3 in 2010 based on the normalized difference vegetation index (NDVI) collected with a Crop Circle ACS-210 active sensor (Holland Scientific Inc. Omaha, Nebraska). The Crop Circle collects and georeferences red and near-infrared reflectance from the ground surface to allow the calculation and mapping of multiple vegetative indices. The sensor was mounted approximately 1.1 m from the soil surface on a custom, single bicycle wheel based platform to achieve a viewing width that corresponded to row width. Data points were collected at 5

Hz on alternating, inter-row spaces (9 inter-rows per plot) and totaled approximately 90-100 NDVI data points per treatment. Georeferencing was accomplished using a Trimble AgGPS® 432 (Trimble Navigation Limited. Sunnyvale, California) with Real Time Kinematic correction (RTK) for accuracy and repeatability of less than 0.05 m. NDVI was calibrated for estimating ground cover using georeferenced digital photos from within the mapped areas. One hundred and eighty-four digital photos, sampled randomly and collected over three years, were quantified for ground cover using a point analysis method based on 63 grid points. The percentage ground cover determined for each photo was regressed against the respective NDVI value at each photo location to produce an equation for estimating ground cover. The NDVI method of estimating ground cover could not be used in the fall as groundcovers were partially or completely senesced and had similar reflectance to bare or partially-bare soil. Thus to collect fall ground cover data four random sample locations were chosen within each plot and a digital photo of inter-row ground cover was taken. Ground cover for the strip-tillage band and the covered inter-row space was individually calculated from each photo to give an estimate of total ground cover from cover species, corn residue cover, and ground cover encroachment into the strip-tillage area. The point analysis method was also used to quantify fall ground cover but due to the number of pictures (700 – 1000 year^{-1}); only 25 grid points per photo were used.

Corn plant height data were collected at 2-3 week intervals, as weather permitted, beginning at V6 and continuing until R1 for 2008 and 2010. Frequent rainfall events early in 2009 prevented initial height measurements until V9 but resumed at approximately the same interval and duration previously specified. Ground cover heights were taken at the same time as corn height but maximum height for most species was achieved at or shortly after corn had reached V6. Mean plot heights were based on 8 random height samples collected with a 3.0 m measuring stick. At harvest, grain and stover were collected from three, random, 1.16 m^2 samples for a total harvest area of 3.48 m^2 per plot. Corn stover was weighed in field and subsampled for moisture correction. Stover, grain, and cob samples were dried to a constant weight at 60 C° and weighed to determine dry matter yield. A miscommunication during 2008 harvest resulted in the loss of cob data for that year.

Statistical analysis

Yield, yield components, and ground cover data were analyzed as a repeated measures split-block in time with the PROC MIXED procedure in SAS (SAS Inst., 2004). All factors were considered fixed with the exception of block and significant differences were determined at the $\alpha = 0.05$ level. Landscape postion was analyzed as the whole plot with species as the sub plot. Year was considered fixed due to the intrinsic interest of perennial ground cover establishment and persistence in following years as well as its effect on corn. Regression analysis to determine the calibration equation for estimating ground cover from NDVI was developed using the PROC REG procedure in SAS (SAS Inst., 2004). Correlations between variables such as corn height measurements, ground cover, cover height, and grain yield were conducted and tested for significance in R (R Development Core Team. 2009) using the Pearson product-moment correlation coefficient method (Pearson, 1896).

Results

Weather

Sorensen Research Station on average receives 570 mm of precipitation and accumulates approximately 2900 growing degree units (GDU's) during a normal growing season. Each of the three study years varied in terms of weather and also deviated from average conditions. In 2008 near average accumulation of GDU's (2779) were achieved from planting to harvest but rainfall totals of 720 mm, of which nearly 40% occurred between planting and June 31, were problematic. Several plots in the toeslope position of the second block were lost in the spring due to flooding. Problems were further compounded by two hail storm events that occurred on June 25 and July 29. The 2009 growing season was comparatively dry due to infrequent rainfall in June and August. Thus, plots only accumulated 0.44 m of precipitation over the growing season. Temperatures were below average as well and resulted in approximately 360 fewer GDU's over the season. In 2010 record rainfalls produced 1.09 m of precipitation over the growing season with about average temperatures producing 3077 GDU's. However, a frost event on May 9, 2010 severely damaged corn at growth stage V2 and delayed corn growth by 7 – 10 days. Leaf damage was not uniform across all treatments, with controls showing less visible damage than perennial ground cover plots. Given that the presence of PGC are normally associated with cool soil conditions in the spring (Martin et al., 1999) and the role of soil thermal emissivity on air and leaf temperatures (Monteith and Unsworth, 2008), such results would be expected under moderate frost conditions.

Over the course of the study period many species failed to establish, or did not persist from year to year. These species were not reseeded in following years as time constraints and poor weather conditions made reseeding difficult (Table 1). Therefore, species comparisons between years are not always possible. Kura clover normally takes up to 3 years to establish acceptable stands, but after three years of corn production, stands were thin and weedy. Other likely reasons for species loss may have been from icesheeting in 2008, low shade tolerance, or their inability to compete with summer annual weeds. Canada bluegrass was the only species to regain acceptable ground cover in 2009 and 2010 after being omitted in 2008.

Fall ground cover data for 2009 and 2010 are provided but must be interpreted with caution (Tables 6 and 11). Corn residue made up a significant portion of the total inter and intra-row space in 2009 and 2010. This is problematic as corn residue may cover plant material of the specified treatment, or bare soil. Therefore, fall cover reported for a particular treatment represents the minimum contribution that could be expected. This also makes it difficult to compare spring and fall cover, and to determine the level of encroachment into the strip-tillage zone.

Species had a significant effect on every variable collected yet it was also involved in 2 and 3 way interactions with landscape position and year among most variables. Due to these interactions, analysis was conducted and presented on a yearly basis.

2008 growing season

Species was the only significant effect on measured variables with the exception of corn height at 22 DAE which also was affected by position. Given that other measurements of corn height that followed showed no influence from this effect it is likely a type I error. Grain yields among 2008 ground cover treatments were all significantly less than the control (Table 2). Alpine bluegrass, white clover, bird's-foot trefoil, and tufted hairgrass were the top 4 ground cover treatments in corn grain production but still reduced yields by 23 - 37%. It should be noted that these species did not persist beyond 2008, but treatments that yielded slightly less than these in 2008 were among the most successful in following years. The lowest yielding species upland bentgrass, redtop, meadow foxtail, and creeping foxtail reduced yields from 77 - 89%. A comparison among the top and bottom 4 species indicates little difference between species in terms of spring ground cover. However, the mature heights of ground covers among higher yielding treatments were usually shorter than the lower yielding treatments (Table 3). Total biomass results were similar to the results of grain yield production in terms to the significance between treatments.

Harvest Index (HI), corn population, and ears plant^{-1} give some indication as to the source of yield reductions (Table 2). Meadow foxtail, redtop, and upland bentgrass treatments significantly reduced corn HI by 13-39% when compared to the control. Corn populations were reduced as well among the four lower yielding treatments with decreases of 16 – 30%. Several other species decreased corn population but none of the top ten yielding treatments were different from the control. Upland bentgrass and redtop were the only two species that yielded fewer ears plant^{-1}. While all ground cover treatments significantly reduced yield the majority of species incurred losses due to factors other than reductions within the selected yield components measured.

Spring ground cover among species varied between 54 and 82 % total cover. In comparison with upland bentgrass, which produced 82 % cover by corn growth stage V4, perennial ryegrass, crested wheatgrass, hard fescue, meadow fescue, white clover, fowl bluegrass, sheep fescue, and riverbank wildrye all provided less cover and ranged from 54 – 67%. All other species were non-significant in relation to the upland bentgrass.

Mature corn height followed the same trend as grain and total biomass yields with respect to ranking with taller corn at maturity normally producing higher yields. At 22 DAE, when first corn height measurements were taken in 2008, the control was significantly shorter than most treatments (Table 3). Of particular interest is that both short and tall ground cover species were among the treatments that showed significant height increases over the control. Mature ground cover height was positively correlated (r = 0.34) with corn height at 22 DAE but quickly deteriorated to a negative relationship by the end of the season (r = -0.36) (Table 4). Spring ground cover showed no relationship (r = 0.02) with corn height at 22 DAE but did become negatively correlated (r = -43) with corn height by the last measurement date. This indicates a possible shade avoidance response induced by changes in quality of reflected light from the ground surface, shading, or a combination of the two. By 42 DAE the control had become significantly taller than all other treatments. An examination of correlation coefficients between corn heights at measurement dates and final grain yields indicate a strengthening positive linear relationship between grain yield and corn height toward maturity (Table 4). This relationship appeared to develop at or prior to 42 DAE as measurements at 22 DAE showed little to no linear relationship with grain yield or following height measurements.

2009 growing season

In 2009 all measured variables were significantly affected by species. A landscape position x species interaction was observed for grain yield and total biomass, with all effects being significant for spring cover (data not shown). As previously discussed, the 2009 growing season was relatively dry yet corn grown within colonial bentgrass, creeping bentgrass, meadow fescue, sheep fescue, hard fescue, tall fescue, meadow fescue, and Canada bluegrass produced significantly higher grain yields than any other year in which they were observed (Table 5). These species were also among the highest yielding treatments during the 2009 season but still reduced yields by 25 – 54% (Table 5). Hard fescue and sheep fescue increased grain yield from summit to toeslope approximately 2 fold. Tall fescue experienced a 36-40% yield reduction in the side-slope position in comparison with the summit and toeslope (data not shown). Total biomass yields and grain yields followed that same basic trend but total biomass was more heavily influenced by stover material for creeping foxtail, meadow foxtail, and upland bentgrass as they had significantly lower harvest indexes in comparison with the control.

Corn population in the control was well above that which was intended. This was a result of volunteer corn from the previous season germinating within the plots. Volunteer corn was observed to only be a problem in the control as it was the only treatment which had been conventionally tilled in the spring. When comparing populations, meadow fescue was chosen for making comparisons as final population (81100 plants ha^{-1}) was approximately equal to the intended population. Therefore, when compared to meadow fescue the 7 lowest corn grain yielding treatments reduced populations by 25 – 47% while other treatments did not differ. Although population clearly contributed to yield loss the ratio of grain DM to cob DM (grain/cob) indicates that some treatments may have affected seed set, seed size, or both. Observation of ears at harvest indicated that the former was likely responsible for the reduction in grain/cob ratio. Only creeping foxtail, meadow foxtail, and riverbank wildrye treatments reduced ears $plant^{-1}$.

Many of the poorer spring ground cover producing species were top in grain yield production and total biomass in 2009 and vice versa for good spring cover producing species (Tables 5 and 6). For example, meadow fescue provided 54% cover which was significantly lower than any treatment, yet it was also the highest yielding among cover treatments (6.3 Mg grain DM ha^{-1}). Red fescue, meadow foxtail, Canada wildrye, and riverbank wildrye, which showed no difference in spring cover producing 78- 85% cover, were among the lowest corn grain producing treatments. Tall fescue did not follow this trend as it was one of the highest yielding (5.0 Mg DM ha^{-1}) treatments as well as one of the higher spring ground cover producers (77%) in 2009. Correlations support the observation that that a negative relationship exists between spring cover and grain yields (-0.51) (Table 7).

Inferences on fall ground cover are difficult to make, yet when one considers the overlapping placement of corn stover and cover supplied by the treatments it appears that most species at the very least maintained similar ground cover to that measured in the spring (Table 6). It is most difficult to support this statement among species such as meadow fescue, tall fescue, and Canada bluegrass as the difference between spring and fall cover is substantial. However, it appears this statement is much more valid among other species, especially when increases in ground cover occur from spring to fall. Regardless, both spring and fall ground cover are correlated (r = 0.63) and both show similar negative linear relationships with grain yield (-0.51 and -0.50, respectively) (Table 7).

Initial corn height measurements taken 33 DAE were correlated (r = 0.56) with final grain yield and this relationship continued to strengthen with taller plants being characteristic of higher yielding plots (Table 7 and 8). This observation supports 2008 observations that early season stressors are responsible for yield reductions as corn height was correlated with final yield early in development.

2010 growing season

Early season frost in 2010 was extremely suppressive to grain yields. All C3 species continued to grow as corn seedlings recovered, giving them a competitive advantage early in the season. As a result, corn yields were reduced by 60 – 91% across all treatments (Table 9). Many of the same species that had done well in the previous years were still among the top yielding despite the adverse conditions created by the frost. The poorer yielding treatment from previous years also retained their rank among species in 2010. Tall fescue, which was very variable in its ranking over the study period was one of the lowest yielding treatments in 2010. As in previous years, total biomass was similar in trend with grain yields but more species were associated with reductions in HI. Unlike 2008 and 2009 populations, ears plant^{-1} and the grain/cob ratios all were associated with higher and lower yielding treatments rather than just the lower yielding treatments. Given that in previous years most treatments that had this effect on yield and yield components were associated with the overly aggressive species indicates that most C3 species can be extremely suppressive if corn growth rate is stalled or reduced by adverse conditions such as frost.

Examination of spring ground cover, fall ground cover, and cover height indicate, as in previous years, that yields are negatively associated with increases in these variables (Table 10 and 11). This is further supported by correlation coefficients of -0.39, -0.45, and 0.40 for the three respective measured variables (Table 12). However, the relationship between spring and fall cover appears much weaker in comparison with 2009 (r = 0.33 vs. 0.63). Much is the same in 2010 in terms of the difficulties in interpreting and comparing fall ground cover with spring cover, but again it appears that cover was at least maintained over the season for most treatments.

Corn height measurements followed the same pattern as in the two previous growing seasons in which a positive linear relationship with grain yield was observed as measurements were taken at later dates in the season. Despite the later initiation of corn height measurements in 2010, evidence that shade avoidance occurred in corn was detected as measurements at 42 DAE were positively correlated with corn height ($r = 0.37$) yet slowly deteriorated and had become negative ($r = -0.15$) by the final corn height measurements (Table 12).

Discussion

The death or the decline of many of these species, regardless of the reason, is evidence against their suitability as PGC for corn in this region of the United States. These results in no way should prevent their use in future studies in locations where more suitable conditions occur. It is the authors opinion, especially after experiencing the variably from season to season, that certain regions offer climates that are better suited for particular perennial ground cover systems to be implemented.

Weather patterns over the three growing seasons likely impacted the success of some treatments through rainfall or temperature. Control plot yields were not significantly different from year to year or between landscape positions within a growing season indicating the stability in corn yields at this location and under these management conditions. However, certain treatments interacted with year due to their inability to maintain constant and uniform growth and development. This was made evident by the observation that the top yield producing treatments in 2009 were significantly shorter in cover height than in any other year in which they were observed. The cause of shorter growing plants may have been the result of slightly dryer conditions or possibly conditions that allowed corn to gain a competitive size advantage early in the season to shade inter-row spaces. Another possibility is that strip-tillage was more effective in suppressing intra-row cover in years following 2008 and possibly suppressed regrowth into the intra-row space. Given that the frost event in 2010 delayed corn growth, it is no surprise that ground cover species would gain an advantage with their cool-season growth habit and be more suppressive. Slight differences in ground cover from season to season were observed among some species but did not always correspond to fluctuations in yield like that of cover height. However, within a particular growing season spring cover was negatively correlated with final grain yield (-0.38 to -0.51). Species whose growth and development varied from year to year, as indicated by the shorter cover heights of high yielding treatments in 2009, also happened to be among the best yield producing treatments from season to season. The variability in growth and development of these species is a fortuitous characteristic. Not only do they allow the highest corn yields but they also provided more flexibility in management under certain growing conditions. Flexibility in this sense can be related to the severity of suppression needed as certain growing conditions such as early spring planting, successful strip-tillage, or optimal growing condition may give corn a competitive advantage and not require as much suppression. Other species such as upland bentgrass, meadow foxtail, creeping foxtail, and redtop are too aggressive and fast growing to give any leniency in timing of management practices to a producer and will undoubtedly require a fast series of back to back events involving mechanical suppression, chemical suppression, and planting to maximize the length of time without competition.

Corn height measurements throughout the season give some indication that final grain yield is influenced by early season stressors. Given that soil fertility and water availability were in ample supply in early spring over the course of this study seems to support the idea that phenotypic constraints are a factor in yield reductions. As to the cause of this phenotype, this may relate to light quality issues from shading, poor quality of lateral reflected light (low r/fr ratio), or a combination of both. This stress occurs prior to 42 DAE as data indicates a positive correlation between cover height and corn height early in 2008 and 2010, which quickly deteriorates into a negative relationship as the seasons progressed. In 2010, this phenomenon was observed to start at 42 DAE, but only after a frost event had damaged and prevented corn from growing for an approximate 10-day period. These are indications shade avoidance may be a factor in yield reductions in these systems.

Species that survived the full length of this study supply sufficient ground cover in the spring given that 0.30 m wide strip-tillage zone would at most allow for 60% cover. Fall ground cover measurements are less informative but support that species at least maintain if not increase cover over the growing season. If suppression of species are not properly achieved, poor growth and development of corn will occur and may be accompanied by reduced populations, lower harvest indexes, fewer harvestable ears, an poor seed set. From observations collected over the three year period, aggressive species or conditions that allow groundcovers to be more competitive for space and light resources lead to these issues. While ground cover increases can be beneficial for soil protection, spreading too fast can be a problem as indicated by significant reductions in population and yield components among most of the species observed in 2010.

Although not quantified, observations of corn growth and development indicate that greater distances between PGC and corn plants produce healthier and taller plants. This was observed especially in 2008 when strip-tillage was first established and resulted in variability between neighboring corn plants. The cause of this phenomenon was that strip-tillage of clump forming grasses uprooted large clumps and created small zones that were wider than the strip-tilled width. These areas could easily be spotted as corn plants were noticeably taller than neighboring plants. Thus is it appears that the proximity of a ground cover species can heavily influence the growth and development of corn. Kumwenda et al. (1993) observed a similar response when varying the widths of a crimson clover PGC with chemical suppression. Other notable observations were striped and chlorotic leaves appearing shortly after emergence in PGC plot but not in the controls, and obvious delays in tasseling in some PGC treatments.

Conclusions

It is suggested, especially given the results of this study that all species will require some type of suppression prior to corn planting to achieve competitive corn yields. It is also important to understand that most species are difficult to initially strip-till, especially in sod forming grasses. Planting in inter-row spaces only will likely be a better practice and lead to a more successful start to the growing season. Although alpine bluegrass, white clover, bird's-foot trefoil, and perennial ryegrass did not persist under these conditions, their success may have been related to the ease in which they could be strip tilled.

Yield appears to be negatively influenced by both plant height and the amount of cover provided by the species in question. Therefore, the choice of a ground cover has to take into account both the vegetative spread rate and the height at maturity. Currently it is difficult to determine what height or what amount of cover can be obtained by a grass or legume yet still be tolerated at a particular growth stage in corn. Over the 3 growing seasons, meadow fescue, fowl bluegrass, and sheep fescue did consistently well relative to other species. If one considers 2009 and 2010 only, species such as colonial bentgrass, and Canada bluegrass can be added to this list of recommended species. These species can be added because difficulties associated with the establishment of Canada bluegrass and difficulties in strip-tillage of colonial bentgrass in 2008 could have been avoided with slight changes in management. Of all the treatments evaluated in this study, these species worked best with corn because of their slow vegetative spread rate and short stature relative to other species. These results indicate that an ideotype for a perennial ground cover would have the following characteristics: low growing, slow green-up in the spring, and little to no vegetative spreading. Although not quantified one could also add characteristics such as summer dormancy and shallow rooting to minimize competition. These characteristics appear to support fundamental needs of corn concerning light quality, competition for resources, and to an extent the critical period of weed control. If these characteristics are not met with the correct ideotype then intensity of suppression must be increased to prevent yield loss.

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Tables

Table 1. Seeding dates, and persistence of ground covers species from 2006-2010

		Cover Establishment†			**Stand Performance‡**		
Common Name	**Cultivar**	**8/15/06**	**05/23/07 - 06/04/07**	**08/17/07**	**2008**	**2009**	**2010**
Crested wheatgrass (*Agropyron cristatum*)	“Highcrest”	S	-	-	A	A	A
Colonial bentgrass (Agrostis capillaris)	“Highland”	S	R	-	A	A	A
Redtop (Agrostis gigantea)		S	R	R	A	A	A
Upland bentgrass (Agrostis perennans)		S	R	R	A	A	A
Creeping bentgrass (Agrostis stolonifera)	“Seaside”	S	R	R	A	A	NP
Creeping meadow foxtail (Alopecurus arundinaceus)	“Garrison”	S	-	R	A	A	A
Meadow foxtail (Alopecurus pratensis)		S	-	-	A	A	A
Sideoats grama (Bouteloua curtipendula)	“Butte”	S	R	R	PE	NP	NP
Blue grama (Bouteloua gracilis)		S	R	R	PE	NP	NP
Buffalograss (Buchloe dactyloides)		S	R	R	PE	NP	NP
Tufted hairgrass (Deschampsia caespitosa)		S	R	R	A	A	A
Canada wildrye (Elymus canadensis)		S	-	-	A	A	A
Riverbank wildrye (Elymus riparius)		S	-	-	A	A	A
Slender wheatgrass (*Elymus trachycaulus*)		S	-	-	A	A	A
Virginia wildrye (Elymus virginicus)		S	-	-	PE	NP	NP
Weeping lovegrass (Eragrostis curvula)		S	R	-	NP	NP	NP
Field fescue (Festuca arvernensis)		S	R	R	PE	NP	NP
Hard fescue (Festuca brevipila)		S	O	-	A	A	A
Sheep fescue (Festuca ovina)		S	O	-	A	A	A
Red fescue (Festuca rubra)		S	O	-	A	A	A
Chewings fescue (Festuca rubra ssp. fallax)		S	O	-	A	A	A
Prairie Junegrass (Koeleria macrantha)		S	R	R	PE	NP	NP
Perennial ryegrass (Lolium perenne)	“Spirit”	S	O	-	A	NP	NP
Bird's-foot trefoil (Lotus corniculatus)	“Norcen”	S	R	-	A	NP	NP
Bulbous canarygrass (Phalaris aquatica)	“Grasslands Maru”	S	R	R	NP	NP	NP
Alpine bluegrass (Poa alpina)		S	O	R	A	NP	NP
Canada bluegrass (Poa compressa)		S	O	-	PE	A	A
Fowl bluegrass (Poa palustris)		S	O	R	A	A	A
Kentucky bluegrass (Poa pratensis)	“Troy”	S	O	R	A	A	A
Rough bluegrass (Poa trivialis)		S	O	R	PE	PE	NP
Tall fescue (Schednnorous phoenix)	“Bulldog 51”	S	O	-	A	A	A
Meadow fescue (Schedonorus pratensis)		S	R	R	A	A	A
Kura clover (Trifolium ambiguum)	“Rhizo”	S	R	-	PE	PE	PE
Crimson clover (Trifolium incarnatum)		S	R	-	NP	U	U
White clover (Trifolium repens)		S	R	R	A	NP	NP

† S = initial seeding; R = reseeded; O = overseeded

‡ A = acceptable (>50% cover); U= unacceptable(<50% cover); PE = poor establishment; NP=non-persistent;

Table 2. Comparison of ground cover species based on yield, yield components and spring cover for the 2008 growing season.

Species	Grain	Total Biomass†	Harvest Index†	Population	Ears Plant^{-1}	Grain/Cob†	Spring Cover
	Mg DM ha-1	Mg DM ha-1	no.	Plants ha-1	no.	no.	%
Alpine bluegrass	7.0 b	10.9 b	0.64 a	84000 a	0.99 ab	-	69 abcdef
White clover	6.6 bc	10.7 bc	0.61 abc	81000 ab	0.96 ab	-	62 def
Bird's-foot trefoil	6.4 bcd	10.1 bcd	0.63 abc	82000 ab	0.98 ab	-	71 abcde
Tufted hairgrass	5.7 bcdef	9.3 bcde	0.61 abcd	77200 abcd	0.96 ab	-	69 abcdef
Perennial ryegrass	5.5 cdef	8.6 cdef	0.65 a	77500 abc	0.99 ab	-	66 bcdef
Kentucky bluegrass	5.0 defg	7.9 defg	0.63 abc	74800 abcd	0.95 ab	-	72 abcde
Crested wheatgrass	4.7 efgh	7.5 efgh	0.62 abc	72000 bcde	1.00 ab	-	64 cdef
Fowl bluegrass	4.4 fghi	7.1 efghi	0.61 abc	81600 ab	0.96 ab	-	62 ef
Riverbank wildrye	4.3 fghi	6.8 fghij	0.62 abc	77100 abcd	0.98 ab	-	54 f
Meadow fescue	3.8 ghij	6.4 ghijk	0.59 bcd	80000 ab	0.99 ab	-	63 cdef
Sheep fescue	3.5 hijk	5.9 hijk	0.58 bcd	67300 defg	0.96 ab	-	60 ef
Tall fesuce	3.5 hijk	5.8 hijkl	0.59 abcd	71700 bcde	0.97 ab	-	69 abcde
Red fescue	3.3 hijkl	5.4 hijklm	0.60 abcd	71100 cde	1.00 ab	-	73 abcde
Creeping bentgrass	3.2 ijkl	5.2 ijklm	0.60 abcd	72000 bcde	1.01 a	-	77 abcd
Chewings fescue	3.1 ijkl	4.9 ijklmn	0.63 abc	63200 efgh	0.98 ab	-	72 abcde
Colonial bentgrass	3.1 ijkl	5.2 ijklm	0.59 abcd	71900 bcde	0.97 ab	-	79 ab
Canada wildrye	3.1 ijkl	5.2 ijklm	0.59 abcd	74600 abcd	0.95 ab	-	72 abcde
Slender wheatgrass	3.0 ijkl	4.8 jklmn	0.61 abc	69200 cdef	0.93 ab	-	69 abcdef
Hard fescue	2.7 jklm	4.4 klmn	0.60 abcd	60600 fgh	1.01 a	-	63 cdef
Creeping foxtail	2.1 klmn	3.8 lmno	0.57 cd	67300 defg	0.91 b	-	73 abcde
Meadow foxtail	2.0 lmn	3.6 mno	0.54 de	61200 fgh	0.92 ab	-	77 abc
Redtop	1.1 mn	2.8 no	0.38 f	59900 gh	0.76 c	-	79 ab
Upland Bentgrass	1.0 n	2.0 o	0.50 e	56160 h	0.78 c	-	82 a
Control	9.1 a	14.7 a	0.62 abc	80000 ab	0.98 ab	-	0 g

Means followed by the same letter are not significant at the 0.05 level

† Cobs are not included in calculation

Table 3. Corn and mature ground cover heights over the 2008 growing season.

	Corn Height (cm)				Ground Cover Height at Cover Species Maturity (cm)
Species	22 DAE	42 DAE	58 DAE	73 DAE	42 DAE
Alpine Bluegrass	-	-	-	-	-
Riverbank wildrye	39 a	77 b	152 bcd	184 bcd	80 gh
Creeping foxtail	37 ab	62 fghij	90 jk	132 kl	93 j
Canada wildrye	36 abc	72 bc	135 def	169 cdefg	103 k
Upland bentgrass	36 abc	44 l	61 l	97 m	74 efg
Tufted hairgrass	36 abc	55 ghij	149 bcd	193 b	69 def
Tall fesuce	35 bcd	58 efgh	111 ghi	156 ghij	84 hi
Redtop	35 bcd	51 ijk	76 kl	113 lm	81 gh
Meadow fescue	35 bcde	57 fghi	110 ghi	162 efgh	80 gh
Perennial ryegrass	34 bcde	72 bc	152 bcd	189 bc	55 bc
Meadow foxtail	34 bcdef	56 fghij	95 ijk	141 ijk	78 fgh
Red fescue	34 bcdef	60 efg	114 gh	159 fghi	59 bc
Creeping bentgrass	34 bcdef	45 kl	83 jk	154 ghij	53 b
White clover	33 bcdef	72 bc	158 bc	198 b	21 a
Bird's-foot trefoil	33 bcdef	77 b	168 b	199 b	28 a
Slender wheatgrass	33 cdef	58 efgh	111 ghi	148 hijk	91 ij
Crested wheatgrass	33 defg	69 cd	143 cde	177 bcdef	68 de
Colonial bentgrass	33 defg	46 kl	93 ijk	137 jk	57 bc
Chewings fescue	32 efgh	51 jk	101 hij	154 ghij	62 cd
Kentucky bluegrass	32 efgh	56 fghij	126 efg	182 bcde	55 bc
Fowl bluegrass	31 fgh	54 ghij	116 fgh	164 defgh	57 bc
Sheep fescue	31 fgh	64 de	123 fg	161 fgh	60 bcd
Hard fescue	30 gh	53 hij	94 ijk	145 hijk	60 bc
Control	29 h	100 a	215 a	236 a	-

Means followed by the same letter are not significant at the 0.05 level
(-) Indicates missing or non-applicable data

Table 4. Correlations between corn heights at different stages of growth, mature ground cover height, spring cover, and final grain yield for 2008.

	22 DAE	**42 DAE**	**58 DAE**	**73 DAE**	**Cover height**	**Spring cover**	**Grain yield**
22 DAE	**1.00**	**0.39**	**0.27**	**0.18**	**0.34**	0.02	0.08
42 DAE	**0.39**	**1.00**	**0.86**	**0.72**	-0.06	**-0.39**	**0.58**
58 DAE	**0.27**	**0.86**	**1.00**	**0.89**	**-0.30**	**-0.47**	**0.81**
73 DAE	**0.18**	**0.72**	**0.89**	**1.00**	**-0.36**	**-0.43**	**0.85**
Cover height	**0.34**	-0.06	**-0.30**	**-0.36**	**1.00**	**0.19**	**-0.52**
Spring cover	0.02	**-0.39**	**-0.47**	**-0.43**	**0.19**	**1.00**	**-0.38**
Grain yield	0.08	**0.58**	**0.81**	**0.85**	**-0.52**	**-0.38**	**1.00**

Bold values are significant at 0.05 level
DAE (days after emergence)

Table 5. Comparison of ground cover species based on yield and yield components for the 2009 growing season.

Species	Grain	Total Biomass	Harvest Index	Population	Ears Plant^{-1}	Grain/Cob
	Mg DM ha^{-1}	Mg DM ha^{-1}	no.	Plants ha^{-1}	no.	no.
Meadow fescue	6.3 b	11.8 b	0.53 abc	81100 abc	0.92 abc	7.3 ab
Colonial bentgrass	5.7 bc	10.4 bc	0.55 a	70200 cdef	0.94 ab	6.7 abcd
Tall fesuce	5.0 bcd	9.3 bcd	0.53 ab	68500 cdef	0.94 ab	6.9 abc
Creeping bentgrass	5.0 bcde	9.2 bcd	0.53 abc	73300 bcdef	0.89 abc	7.0 abcd
Canada bluegrass	4.9 bcde	8.9 bcd	0.55 a	70000 cdef	0.97 a	6.8 abcd
Sheep fescue	4.6 bcde	8.6 cde	0.51 abc	72700 cdef	0.90 abc	6.5 abcdef
Fowl bluegrass	4.2 cdef	7.9 cdef	0.51 abc	78800 abcd	0.90 abc	6.4 abcdef
Tufted hairgrass	4.0 cdefg	7.6 cdef	0.50 abc	76100 abcde	0.91 abc	6.3 abcdef
Hard fescue	3.9 defg	7.2 defg	0.52 abc	67600 cdef	0.90 abc	6.6 abcde
Kentucky bluegrass	3.7 defg	7.3 defg	0.49 abc	72000 cdef	0.89 abc	6.2 abcdef
Chewings fescue	3.4 efg	6.7 defgh	0.50 abc	68500 cdef	0.86 abcd	6.1 abcdef
Crested wheatgrass	3.0 fgh	5.9 efghi	0.49 abc	64700 cdefg	0.83 abcd	5.5 def
Canada wildrye	2.7 fgh	5.2 fghi	0.50 abc	67300 cdef	0.79 bcd	6.2 abcdef
Riverbank wildrye	2.6 fghi	5.4 fghi	0.45 abc	61000 efg	0.77 cd	5.8 cdef
Red fescue	2.6 ghi	4.8 ghij	0.50 abc	63800 defg	0.80 abcd	5.8 cdef
Slender wheatgrass	2.2 ghij	4.2 hijk	0.48 abc	63800 defg	0.80 abcd	5.3 f
Redtop	1.7 ghij	3.4 ijk	0.46 abc	58700 efg	0.81 abcd	5.9 bcdef
Upland bentgrass	1.6 hij	3.3 ijk	0.43 bc	58000 fgh	0.81 abcd	5.4 ef
Meadow foxtail	1.1 ij	2.2 jk	0.43 c	49400 gh	0.70 d	5.3 f
Creeping foxtail	0.7 j	1.9 k	0.23 d	42700 h	0.42 e	3.6 g
Control	8.4 a	15.2 a	0.55 a	93100 a	0.90 abc	7.3 a

Means followed by the same letter are not significant at the 0.05 level

Table 6. Comparison of cover treatments for total spring and fall ground cover and cover in the inter and intra-row zones for 2009

	Spring Cover	**Total Fall Cover (%)**			**Strip-tillage Zone Cover (%)**			**Inter-row Cover (%)**		
Species	Species Cover	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil
Red fescue	85 a	74 abc	19 bcde	7 a	66 ab	26 abcd	7 a	79 abcde	14 bcde	7 abc
Meadow foxtail	81 ab	82 a	9 a	9 abc	71 a	16 a	13 abcd	89 a	5 a	6 ab
Canada wildrye	78 abc	65 bcde	19 bcde	16 ef	51 cde	27 bcd	22 de	75 bcdef	14 abcde	12 cdef
Riverbank wildrye	78 abc	60 def	24 def	16 ef	50 cde	32 cde	18 de	67 def	23 ef	15 ef
Chewings fescue	77 bcd	74 abc	19 bcde	7 a	58 abcd	32 cde	10 ab	85 abc	10 abcd	5 a
Tall fesuce	77 bcd	62 cdef	23 def	15 def	45 def	35 de	20 de	74 bcdef	15 bcdef	11 bcdef
Upland bentgrass	76 bcd	77 ab	12 ab	10 abcd	62 abc	21 abc	16 cd	88 ab	7 a	6 ab
Redtop	75 bcde	70 abcd	17 abcd	13 bcde	55 bcde	26 abcd	19 de	80 abcd	11 abcd	9 abcde
Crested wheatgrass	75 bcde	55 ef	25 def	19 f	41 ef	35 de	23 ef	64 f	19 def	17 f
Creeping foxtail	74 bcdef	77 ab	13 abc	10 abcd	65 ab	20 ab	14 bcd	85 abc	8 abc	7 abc
Slender wheatgrass	73 bcdef	67 bcde	20 bcde	13 bcde	51 cde	31 cde	17 de	78 abcde	12 abcd	10 abcde
Kentucky bluegrass	73 cdefg	68 bcd	22 cdef	10 abcd	50 cde	36 de	13 abcd	81 abcd	12 abcd	8 abcd
Canada bluegrass	70 defgh	50 fg	36 g	15 def	32 fg	51 f	18 de	61 fg	25 f	14 def
Sheep fescue	69 efgh	65 bcde	25 def	10 abcd	45 def	41 ef	14 abcd	78 abcde	14 abcde	8 abcd
Tufted hairgrass	67 efgh	68 bcde	21 bcdef	10 abcde	52 bcde	34 de	12 abcd	79 abcde	12 abcde	9 abcde
Fowl bluegrass	67 fgh	61 cdef	25 def	14 cdef	46 def	36 de	18 de	71 cdef	18 cdef	11 abcdef
Colonial bentgrass	66 gh	62 cdef	27 efg	10 abcde	46 def	41 ef	13 abcd	72 cdef	18 cdef	9 abcde
Creeping bentgrass	66 gh	72 abcd	20 bcde	8 ab	62 abc	29 bcd	10 ab	80 abcde	14 abcde	7 abc
Hard fescue	65 h	73 abcd	19 bcde	8 ab	56 bcd	34 de	10 ab	84 abc	10 abcd	6 abc
Meadow fescue	54 i	38 g	32 fg	27 g	24 g	44 ef	30 f	48 g	24 ef	25 g
Control	0 j	0 h	-	-	0 h	-	-	0 h	-	-

Means followed by the same letter are not significant at the 0.05 level
(-) Indicates missing or non-applicable data

Table 7. Correlations between corn heights at different stages of growth, mature ground cover height, spring cover, and final grain yield 2009.

	33 DAE	**41 DAE**	**53 DAE**	**63 DAE**	**76 DAE**	**Cover ht.**	**Spring cover**	**Fall cover**	**Grain yield**
33 DAE	**1.00**	**0.82**	**0.75**	**0.68**	**0.62**	**-0.28**	**-0.32**	**-0.40**	**0.56**
41 DAE	**0.82**	**1.00**	**0.89**	**0.86**	**0.78**	**-0.43**	**-0.52**	**-0.53**	**0.73**
53 DAE	**0.75**	**0.89**	**1.00**	**0.94**	**0.87**	**-0.50**	**-0.51**	**-0.54**	**0.82**
63 DAE	**0.68**	**0.86**	**0.94**	**1.00**	**0.92**	**-0.55**	**-0.52**	**-0.53**	**0.85**
76 DAE	**0.62**	**0.78**	**0.87**	**0.92**	**1.00**	**-0.62**	**-0.49**	**-0.48**	**0.88**
Cover height	**-0.28**	**-0.43**	**-0.50**	**-0.55**	**-0.62**	**1.00**	**0.49**	**0.30**	**-0.65**
Spring cover	**-0.32**	**-0.52**	**-0.51**	**-0.52**	**-0.49**	**0.49**	**1.00**	**0.63**	**-0.51**
Fall cover	**-0.40**	**-0.53**	**-0.54**	**-0.53**	**-0.48**	**0.30**	**0.63**	**1.00**	**-0.50**
Grain yield	**0.56**	**0.73**	**0.82**	**0.85**	**0.88**	**-0.65**	**-0.51**	**-0.50**	**1.00**

Bold values are significant at 0.05 level
DAE (days after emergence)

Table 8. Corn and mature ground cover heights over the 2009 growing season.

	Corn Height (cm)					Ground Cover Height at Maturity (cm)
Species	33 DAE	41 DAE	53 DAE	63 DAE	76 DAE	33 DAE
Meadow fescue	55 ab	89 b	126 b	184 b	216 ab	58 g
Tall fescue	51 bc	80 bc	120 bc	163 bc	198 bc	54 gh
Colonial bentgrass	49 bcd	77 c	108 cd	157 bcd	198 bc	48 ghi
Creeping bentgrass	47 cde	70 cd	101 de	137 cde	179 cd	38 j
Redtop	46 cdef	64 def	79 fgh	97 ghij	125 ghi	85 bc
Riverbank wildrye	45 defg	64 def	89 efg	120 efg	151 defg	78 cde
Canada bluegrass	45 defgh	63 defg	89 efg	129 def	142 efgh	46 hij
Kentucky bluegrass	44 efghi	63 defgh	88 efg	124 ef	170 cd	56 g
Crested wheatgrass	44 efghi	64 def	85 fg	116 efg	155 def	70 f
Fowl bluegrass	42 efghi	60 efgh	82 fgh	121 efg	172 cd	57 g
Canada wildrye	42 efghi	63 defg	86 fg	112 efgh	142 efgh	76 def
Tufted hairgrass	42 efghi	69 cde	93 de	123 efg	178 cd	76 cdef
Upland bentgrass	42 fghi	57 fgh	75 gh	89 hij	116 hij	72 ef
Chewings fescue	41 ghi	61 defgh	80 fgh	119 efg	166 de	51 ghi
Sheep fescue	41 ghi	61 efgh	91 ef	133 de	177cd	46 hij
Hard fescue	39 hij	63 defg	84 fgh	117 efg	164 de	45 ij
Red fescue	39 ij	56 fghi	75 gh	104 fghi	140 efgh	57 g
Creeping foxtail	39 ij	53 hi	70 hi	86 ij	101 ij	100 a
Slender wheatgrass	36 j	54 hi	73 ghi	98 ghi	132 fgh	81 bcd
Meadow foxtail	35 j	47 i	59 i	72 j	93 j	88 b
Control	58 a	107 a	150 a	213 a	234 a	-

Means followed by the same letter are not significant at the 0.05 level
(-) Indicates missing or non-applicable data
DAE(days after emergence)

Table 9. Comparison of ground cover species based on yield and yield components for the 2010 growing season.

Species	Grain	Total Biomass	Harvest Index	Population	Ears Plant^{-1}	Grain/Cob
	Mg DM ha-1	Mg DM ha-1	no.	Plants ha-1	no.	no.
Canada bluegrass	3.4 b	6.0 bc	0.57 a	65400 ab	0.84 abcdef	5.8 ab
Sheep fescue	3.2 bc	5.7 bcde	0.57 a	59300 bcdef	0.89 ab	5.8 ab
Colonial bentgrass	3.2 bcd	6.2 b	0.52 abc	62700 abcd	0.79 abcdef	5.4 bcde
Fowl bluegrass	3.2 bcd	5.7 bcde	0.53 abc	60200 bcde	0.82 abcdef	5.5 bcd
Slender wheatgrass	3.1 bcd	5.4 bcde	0.55 ab	59300 bcdef	0.77 bcdef	5.8 abc
Meadow fescue	3.1 bcde	5.7 bcde	0.55 abc	53900 bcdefg	0.82 abcdef	6.0 ab
Kentucky bluegrass	2.9 bcde	5.4 bcde	0.52 abc	60300 bcde	0.78 bcdef	5.8 ab
Hard fescue	2.8 bcde	5.0 bcdef	0.56 ab	60900 bcd	0.80 abcdef	5.7 abc
Crested wheatgrass	2.7 bcde	4.9 bcdefg	0.54 abc	52200 cdefg	0.89 abcd	5.2 bcde
Chewings fescue	2.6 bcde	4.7 bcdefg	0.54 abc	64100 abc	0.89 abc	5.3 bcde
Tufted hairgrass	2.6 bcdef	5.1 bcdef	0.48 abcd	53600 bcdefg	0.87 abcde	4.9 bcde
Canada wildrye	2.1 bcdefg	4.0 bcdefgh	0.46 abcd	48100 efg	0.69 defg	4.8 bcde
Riverbank wildrye	1.8 cdefg	4.0 bcdefgh	0.45 bcde	50600 defg	0.70 bcdef	4.4 ef
Upland bentgrass	1.7 defg	3.7 cdefgh	0.46 bcd	56700 bcdef	0.68 efg	4.8 cde
Redtop	1.7 defg	3.5 defgh	0.48 abcd	55700 bcdefg	0.67 efg	4.6 def
Tall fesuce	1.5 efg	3.3 defgh	0.43 cde	47300 fg	0.66 fg	4.4 ef
Red fescue	1.5 fg	3.0 fgh	0.50 abc	55500 bcdefg	0.70 def	4.9 bcde
Creeping foxtail	1.1 fg	2.6 gh	0.35 e	44300 g	0.50 g	4.6 def
Meadow foxtail	0.8 g	2.1 h	0.37 de	47800 fg	0.65 fg	3.7 f
Control	8.5 a	15.0 a	0.57 a	74000 a	0.98 a	6.7 a

Means followed by the same letter are not significant at the 0.05 level

Table 10. Corn and mature ground cover heights over the 2010 growing season..

	Corn Height (cm)				Ground Cover Height at Maturity (cm)
Species	42 DAE	57 DAE	71 DAE	88 DAE	57 DAE
Tall fescue	36 b	69 b	105 c	153 cde	82 bcd
Meadow fescue	35 bc	-	150 b	186 b	-
Crested wheatgrass	33 bcd	60 bcd	99 cde	154 cde	79 bcd
Redtop	32 bcde	60 bcd	91 cdef	143 def	75 cde
Creeping foxtail	32 cdef	56 cde	81 defg	132 efg	96 a
Riverbank wildrye	31 cdef	61 bcd	102 cd	166 bcd	86 abc
Canada bluegrass	31 cdefg	61 bcd	103 cd	157 bcde	62 fgh
Canada wildrye	30 cdefg	62 bcd	102 cd	154 cde	62 fgh
Fowl bluegrass	30 cdefg	64 bcd	108 c	164 bcd	61 fghi
Tufted hairgrass	29 defgh	59 bcd	101 cd	160 bcd	84 bc
Kentucky bluegrass	29 defgh	59 bcd	92 cdef	160 bcd	54 hi
Slender wheatgrass	29 defgh	65 bc	104 c	157 bcde	72 def
Colonial bentgrass	29 defgh	61 bcd	110 c	176 bc	49 ij
Meadow foxtail	28 efgh	46 e	66 g	114 g	89 ab
Chewings fescue	28 fgh	59 bcd	92 cdef	151 cde	59 ghi
Upland Bentgrass	26 ghi	51 de	78 efg	132 efg	65 efg
Sheep fescue	26 hi	58 bcd	92 cdef	158 bcd	49 ij
Hard fescue	26 hi	52 de	80 defg	146 def	43 j
Red fescue	23 i	47 e	72 fg	121 fg	52 hij
Control	43 a	111 a	206 a	228 a	-

Means followed by the same letter are not significant at the 0.05 level
DAE (days after emergence)

Table 11. Comparison of ground cover species based on spring and fall ground cover and fall ground cover classes in inter and intra-row zones for 2010.

	Spring Cover	Total Fall Cover (%)			Strip-tillage Zone Cover (%)			Inter-row Cover (%)		
Species	Species Cover	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil
Chewings fescue	76 a	75 abc	21 abcde	4 ab	54 abcde	38 abcd	8 ab	89 a	9 ab	2 a
Meadow foxtail	75 a	78 ab	14 a	8 abcde	61 abc	27 a	12 abcd	89 a	5 a	5 abcd
Red fescue	72 ab	81 a	16 abc	4 a	69 a	26 a	5 a	90 a	7 ab	3 ab
Upland bentgrass	69 abc	76 ab	17 abc	9 abcde	61 abcd	29 ab	10 abcd	87 ab	8 ab	5 abcd
Canada bluegrass	69 abc	63 cde	25 cde	12 ef	36 fg	46 d	19 def	82 abcd	11 abcd	8 bcdef
Tufted hairgrass	69 abc	64 cde	29 ef	7 abcde	44 defg	46 d	10 abcd	77 bcd	18 cde	6 abcde
Redtop	69 abcd	70 abcde	19 abcd	11 de	55 abcde	30 ab	15 bcde	80 abcd	12 abcd	9 def
Tall fesuce	68 abcd	71 abcd	18 abc	11 cde	57 abcde	32 abc	11 abcd	81 abcd	9 abc	10 fg
Creeping foxtail	68 abcd	76 abc	16 abc	8 abcde	65 ab	26 a	9 abc	83 abc	10 abcd	7 abcdef
Riverbank wildrye	68 abcd	58 efg	29 ef	13 ef	36 fg	46 d	18 cdef	73 cd	18 cde	9 def
Crested wheatgrass	68 abcd	47 g	35 f	18 fg	32 g	45 cd	23 ef	57 f	29 f	14 gh
Kentucky bluegrass	67 abcd	78 ab	17 abc	6 abcd	59 abcd	33 abc	8 ab	90 a	6 ab	4 abc
Canada wildrye	66 bcde	58 efg	25 ef	12 ef	42 efg	41 bcd	18 cdef	69 de	23 ef	8 cdef
Colonial bentgrass	64 bcde	68 bcde	25 cde	7 abcde	48 bcdefg	41 bcd	10 abcd	81 abcd	14 abcde	5 abcd
Slender wheatgrass	63 bcdef	61 def	29 ef	10 bcde	46 cdefg	44 cd	10 abcd	71 de	19 de	10 efg
Hard fescue	62 cdef	76 ab	19 abcd	5 abc	59 abcd	34 abcd	7 ab	88 ab	9 ab	4 ab
Sheep fescue	59 def	71 abcd	21 abcde	7 abcde	52 abcdef	38 abcd	10 abcd	84 abc	11 abcd	6 abcde
Fowl bluegrass	57 ef	66 bcde	24 bcde	9 abcde	46 cdefg	38 abcd	15 bcde	79 abcd	15 bcde	5 abcde
Meadow fescue	53 f	48 fg	28 def	23 g	32 g	41 bcd	26 f	60 ef	19 def	19 h
Control	0 g	0 h	37 f	63 h	0 h	61 e	39 g	0 g	21 ef	79 i

Means followed by the same letter are not significant at the 0.05 level

Table 12. Correlations between corn heights at different stages of growth, mature ground cover height, spring cover, and final grain yield 2010.

	42 DAE	**57 DAE**	**71 DAE**	**88 DAE**	**Cover height**	**Spring cover**	**Fall cover**	**Grain yield**
42 DAE	**1.00**	**0.66**	**0.59**	**0.47**	**0.37**	**-0.16**	**-0.46**	**0.20**
57 DAE	**0.66**	**1.00**	**0.90**	**0.74**	-0.01	**-0.49**	**-0.48**	**0.58**
71 DAE	**0.59**	**0.90**	**1.00**	**0.82**	-0.05	**-0.49**	**-0.58**	**0.67**
88 DAE	**0.47**	**0.74**	**0.82**	**1.00**	-0.15	**-0.33**	**-0.56**	**0.76**
Cover height	**0.37**	-0.01	-0.05	**-0.15**	**1.00**	**0.25**	**-0.17**	**-0.40**
Spring cover	**-0.16**	**-0.49**	**-0.49**	**-0.33**	**0.25**	**1.00**	**0.33**	**-0.39**
Fall cover	**-0.46**	**-0.48**	**-0.58**	**-0.56**	**-0.17**	**0.33**	**1.00**	**-0.45**
Grain yield	**0.20**	**0.58**	**0.67**	**0.76**	**-0.40**	**-0.39**	**-0.45**	**1.00**

Bold values are significant at 0.05 level
DAE (days after emergence)

CHAPTER 4: RED/FAR-RED EFFECT ON CORN GROWTH AND DEVELOPMENT IN PERENNIAL GROUND COVERS

A paper to be submitted to Crop Science

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Abstract

Perennial ground covers (PGC) grown with corn can play an important role in soil conservation, but poor growth and development of corn is observed unless covers are chemically or mechanically suppressed. One explanation for this poor growth has been linked to low red/far-red (r/fr) light reflected from ground covers. While growth chamber studies have been conducted to separate low r/fr light effects from resource competition, few field studies have been conducted. To accomplish these goals the authors used a combination of rolled Kentucky bluegrass (*Poa pratensis* L.) sod placed between rows at planting, two experimental corn cultivars with differing sensitivity to PGC, and irrigation to determine the effects of low r/fr light on strip-tilled corn. The objectives of this study were to: i) determine the effect of low r/fr reflectance on corn growth and development in a strip-tilled system ii) determine how timing (V-stage) of low r/fr reflectance affects corn growth and development in strip-tilled systems. Yield and yield components among treatments did not statisitically differ ($\alpha = 0.05$), but significant reduction in leaf transmittance, LAI, and mature corn height between sod treatments indicate that early detection of PGC by corn may affect growth and development. These results indicate that corn has some sensitivity to PGC despite having a 0.30 m cover free zone to grow, however, corn plants appeared to compensate as yield reduction was considered insignificant based on statistical analysis.

Introduction

Perennial ground covers (PGC) are annual or perennial plants inter-seeded with a row crop to confer an ecological, economical, or environmental benefit to the production system (Flynn et al., 2011). The use of PGC in crop production arises from their effect on reducing soil erosion and runoff from agricultural fields, but their benefits are farther reaching as they have also been linked to reductions in weed populations (Palada et al., 1982; Enache and Ilnicki, 1990), and increases in predatory insects (Prasifka et al., 2006; Schmidt et al., 2007) and soil microbial biomass (Jäggi et al., 1995*)*. However, their success in corn production has been limited as grain yields are significantly reduced unless management practices are altered to meet the systems requirements. The success of PGC has usually been accomplished by chemical suppression, mechanical suppression or a combination of the two during the initial stages of development (Adams et al., 1970; Martin et al., 1999; Zemenchik et al., 2000) or seeding of ground cover species 10 – 20 days post emergence (Scott et al., 1987; Abdin et al., 2000). This appears to agree with several studies that suggest that corn is most sensitive to competition early in development (Evan et al., 2003). Failure to suppress PGC during early corn development has resulted in yield reductions of 48 – 100% (Elkins et al., 1983; Eberlein et al., 1992). Thus, chemical and mechanical suppression is a necessity in these cropping systems.

Resource competition has been credited for corn grain yield reductions when weeds or PGC occupy the intra- and inter-row spaces (Eberlein et al., 1992; Liedgen et al., 2004). However, an increasing body of evidence in the literature suggests the low red/far-red ratios associated with light reflected from neighboring weeds or ground covers may play a significant role in reducing corn yield. Since the hypothesis was first introduced by Rajcan and Swanton (1997) several studies have linked reductions in r/fr to changes in growth and development of corn that are believed to result in phenotypic constraints on yields (Rajcan et al., 2004; Page et al., 2009; Page et al., 2010). Others have also suggested that low r/fr is associated with the critical period of weed control (CPWC) in corn as corn yields are most sensitive to competition between VE and V5 with little reduction in yield if weeds emerge after V5 (Evans et al., 2003; Page et al., 2009). Evidence of phenotypic changes appear early in development and thus overlap the CPWC. Changes to the corn plants include reductions in shoot/root ratios (Kasperbauer and Karlen, 1994), and increases in corn seedling heights (Page et al., 2009). Other possible changes that may occur in corn but have only been observed in other species include: increased leaf transmittance, reduced starch grain numbers and size, and fewer stomata (Kasperbauer and Peaslee, 1973; Kasperbauer and Hunt, 1992; Heraut-Bron et al., 1999). While shoot/root ratios appear to eventually regain normal relative proportions, plant growth rates become suppressed and produce shorter mature plants relative to normal r/fr light controls (Liu et al., 2009).

Proximity of PGC to corn rows may also play a role in r/fr signaling. Flynn et al. (2011) observed that variability in corn heights between neighboring plants was many times associated with the distance between the corn plant and the PGC. In this particular case strip-tillage in clump forming grasses uprooted entire clumps and created a wider strip-tillage zone within intra-row areas. When this occurred, corn plants appeared a darker green than neighboring plants, and reached a taller mature height. While less ground cover may coincide with warmer soil temperatures and possibly uneven emergence, this was not observed to be the case. Kumwenda et al. (1993) also observed this phenomenon while varying widths of band suppression in crimson clover, stating that between 20 - 40% cover had no effect on corn grain yield. Undoubtedly PGC height can play a significant role in this proximity phenomenon due to the interception of radiation, but even low growing covers appear to affect corn growth and development (Flynn et al., 2011).

Greenhouse and growth chamber studies have attempted to measure the effect of low r/fr reflectance on corn seedlings in the absence of competition. However, these studies do not translate well to conditions experienced in the field. This is especially true with PGC as mechanical suppression is often used to create a cover free zone for corn seedlings to grow and develop and thus places the source of low r/fr reflectance farther from the corn row. Thus several questions need to be answered in order to determine if low r/fr reflectance is a factor in determining yield under strip-tillage practices. To accomplish this the authors used a combination of irrigation and rolled Kentucky bluegrass sod at different stages of development to i) determine the effect of low r/fr reflectance on corn growth and development in a strip-tilled system ii) determine how timing (V-stage) of low r/fr reflectance affects corn growth and development in strip-tilled systems. Answering these questions may help separate resource competition from light quality issues in past and future studies as well as lead to a better understanding of the components required for a successful corn crop grown with a perennial ground cover without the need of chemical suppression.

Materials and Methods

Location characteristics

Field experiments were conducted in 2009 at the Sorensen Research Station near Boone, IA (42°00'N, 93°44'W, 330 m above sea level). At the Sorensen location a lack of irrigation required transportation of irrigation tanks and sprinkler heads 3 to 4 times per week to the study site to maintain plots. In 2010, plots where moved to the Hinds Research Station near Ames, IA (42° 03 ’N, 93°38’ W, 275 m above sea level) where irrigation availability allowed plots to be managed with less labor than in 2009. Plot soils at the Sorensen site consisted of a Clarion loam (2% slope, fine-loamy, mixed superactive, mesic Typic Endoaquolls), while the Hinds location plots were made up of a Coland clay loam (0-2% slope, fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls). At both locations, soybean had been the previous season’s crop.

Management

Five cover treatments and two experimental corn hybrids were arranged in a split-plot design with cover treatments as the whole plot and corn (*Zea mays* L.) hybrid as the subplot. Cover treatments included a conventionally tilled control and four Kentucky bluegrass (*Poa pratensis* L.) sod treatments placed at two week intervals starting at VE and ending at V6. The sod was installed in precut, 0.46 m x 1.82 m rolls in the middle of the inter-row space to simulate a PGC with a 0.30 m strip-tillage zone. Applying bluegrass sods in this manner prevented early season competition for soil resources, while also minimizing the growth rate of bluegrass to prevent shading. The two experimental corn varieties were planted on May 21, 2009 and May 24, 2010 with a four-row Kinze 3000 pull type planter (Kinze Mfg, Iowa City, Iowa) in 3.0 m x 4.6 m plots on 0.76 m row spacing’s at populations of 80,000 seeds ha^{-1}. Experimental corn varieties used in 2009 were designated entries 12 and 18 and were chosen due to their sensitivity to PGC in a previous experiment (Bowden et al., 2011). In 2010 seed stock of entry 18 was in limited supply due to previous year production problems and a substitute designated entry 8 was chosen due to similar performance as reported by

Bowden et al.(2011). The 2010 entries were planted in the same manner as the previous year. Entries 8, 12, and 18 had been chosen for comparison based on observations from the 2008 growing season in which entries 8 and 18 incurred greater yield reductions than entry 12 in the presence of a bluegrass ground cover. Thus these entries were chosen in an attempt to elicit an interaction with cover treatments.

Urea ($CO(NH_2)_2$) was applied at the equivalent of 168 kg ha^{-1} N in both years. Phosphorus (P) and potassium (K), in the forms P_2O_5 and K_2O, respectively, were applied based on soil tests and soil fertility recommendations by Iowa State University Extension (Sawyer et al., 2002). All soil amendments were broadcast applied prior to planting with a Gandy Model 62 Series air-delivery fertilizer system (Gandy Company, Owatonna, MN). To control weeds, a combination of hand weeding and broadcast application of glyphosate [N-(phosphonomethyl) glycine] at 3.0 kg ai ha^{-1} was used. If glyphosate was applied to plots containing sod, then a hand sprayer was used to band apply herbicide so that the sod would remain unharmed. In 2010 Japanese beetles (*Popillia japonica* Newman) began to feed on corn silks and were controlled by a hand spray application of Dimethoate (0,0-dimethyl S-[N-(methylcarbamoyl) Methyl] phosphorodithioate) at 0.6 kg ai ha^{-1}. In the absence of rainfall, plots were irrigated at a rate of 22 mm every 2-3 days during the first 10 weeks of the study with a riser irrigation system. The frequency of these irrigation events was needed in order to maintain the sod. Once the corn canopy closed, sod maintenance was minimal as frequency of rainfall events and shallow rooting of the sod provided sufficient water.

Data collection

Corn plant height data were collected at 2-3 week intervals, as weather permitted, beginning at V6 and continuing until R1 in both years. Mean plot heights were based on 8 random height samples collected with a 3.0 m measuring stick. In 2009 weather permitted five dates on which corn height measurements could be taken but extreme rainfall events in 2010 prevented excess foot traffic and only permitted 3. Spad meter measurements were collected with a SPAD 502 chlorophyll meter (Spectrum Technologies, Inc., Plainfield, Illinois) at V6, V8, V13, V18, and R1 in 2009 to determine the relative transmittance between treatments but again rainfall events 2010 permitted only one spad measurement at V12. Leaf area index (LAI) measurements were also taken in 2009 with a LI-COR 2000 area analyzer (LI-COR Environmental**,** Lincoln, Nebraska) at corn growth stages V8 and R1 but none were taken in 2010. Measurements of sod r/fr reflectance was collect with a Fieldspec Handheld (ASD Inc, Boulder, CO) during initial installment of sod and again prior to corn tasseling. At harvest, grain and stover were collected from a 2.3 m sample area, which was comprised of 2, 1.15 m^2 harvests from each of the two center rows. Because of the small plot size the center of each plot was harvested to avoid edge effects. Corn stover was weighed in the field and subsampled for moisture correction. Stover, grain, and cob samples were dried to a constant weight at 60 C° and weighed to determine dry matter yield. Six random ears from each plot were sampled to determine the number of rows and kernels per row produced by each treatment.

Statistical analysis

Because of the issues with seed stock and the movement of locations between 2009 and 2010, each year was analyzed separately. Yield, yield components, Spad measurements and LAI data were analyzed with the PROC MIXED procedure in SAS (SAS Inst., 2004). Sod treatments represented the main plot, while corn variety represented the subplot. All factors were considered fixed with the exception of block and significant differences were determined at the $\alpha = 0.05$ level.

Results

Weather conditions varied greatly between the 2009 and 2010 growing seasons with 2009 being relatively cool throughout the spring and summer, but becoming dry after late June. Weather in 2010 produced frequent and high levels of rain fall with air temperatures relatively normal. Thus, the 2009 growing season produced 0.41 m of rainfall (0.13 m below normal) and 2553 growing degree units (GDU's) (364 below normal), while 2010 produced 1.1 m of rainfall (0.52 m above normal) and 3077 GDU's (134 above normal). However, weather condition in 2010 caused more restrictions in data collection frequency as soil condition were constantly saturated and would have resulted in damage to the sod from foot traffic. Thus the 2010 data set lacks the amount of information that was collected in 2009.

Sod treatments appeared to work well in terms of remaining viable under weather and management conditions and produced a r/fr ratios ranging from 0.05 - 0.20 and maximum sod heights of 0.18 m over the growing season. However, it should be noted that this represents the r/fr of the bluegrass canopy only and does not take into consideration the bare soil under the corn canopy which had a higher r/fr ratio (0.80 – 1.00). The ratio of r/fr as perceived by the corn canopy is difficult to quantify due to the lack of data in the literature. Therefore it is difficult to outline how close in proximity a low r/fr material needs to be in relation to a corn canopy, or the proportion of red to far-red light needed to induce changes in growth. In 2009 and 2010 the sod had developed a sufficient root system by corn growth stage VT, however, the root mass produced was not extensive enough to prevent the sod from being removed manually. This was rather encouraging as it suggests below ground competition was minimized for most of the growing season.

Sod treatments did not have a significant effect on grain yield or total biomass in either year (Table 1 and 2). However, sod treatments did have an effect on final corn height and Spad values in both 2009 and 2010 (Table 3 and 4). Spad values indicate that leaf transmittance was greater for the VE sod treatments in comparison with the control at each collection date in 2009. In 2010 the VE, V2, and V6 treatments all exhibited more leaf transmittance in relation to the control. Unfortunately this was the only recorded spad measurement taken in 2010. In comparison with the control, final corn height was not significantly affected for the VE sod treatment in 2009 and 2010. The V6 treatment was significantly taller than the VE treatment in 2009 and the V2 treatment was significantly shorter than all treatments in 2010. While these observations may be an indication of some type of interaction between the plant and the timing of light stress it is more likely that this is a type I error. Other notable effects were: reduced LAI at R1 for the VE and V4 treatments in 2009, and an increased HI for VE and V2 treatments in 2010.

There was no evidence of a statistical difference between corn cultivars in terms of grain or total biomass yields in either year yet differences in corn height (all dates) and number of kernel rows produced were greater for entry 12 in both years. In 2009 entry 12 also had a greater HI, and a greater LAI at V8 in comparison with entry 18. Entry 12 also produced more ears plant^{-1} in 2010 than entry 8 (1.0 and 0.98, respectively). A two way interaction with cultivar and sod treatment was detected in 2009 for the number of kernels row^{-1}. It appears that the sod treatment at V4 resulted in approximately 4 more kernels per row for entry 18 than entry 12 at this time and approximately 5 – 6 more kernels per row than any other sod treatment for entry 18. Again this may represent an interaction between time of treatments and the variety or possible a type I error.

Discussion

The imposed sod treatments appeared to effect corn growth and development by increasing leaf transmittance, reducing final corn height, and reducing LAI at reproductive stages but only if the treatment was applied at or prior to V4. Treatments imposed were set to minimize below ground competition while reducing light quality by means of laying sod for instant reduction in the red/far-red ratio. Therefore, it is likely that these responses are the result of low r/fr ratios. The effect of the sod, which was confined to the center 18 inches of the inter-row space, did not reduce yields significantly indicating that the plant was able to compensate or that the r/fr signal received was not sufficient to alter corn growth and development to the extent that yield was impacted. Another possibility is that the proximately and the short height of the sod minimized corn exposure to low r/fr light and prevented a response.

In summary, if PGC can be maintained at a low growing height while preventing vegetative spreading, decumbent growth, or from leaves growing over or laying in the strip tillage zone, then much of the effect of low r/fr can be minimized. It may also be deduced that if a sufficient strip-tillage distance and PGC height can be determined for a particular corn variety that any reduction in yield may be overcome by increasing below ground resources, assuming no alleochemical effects.

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Tables

Table 1. Yield and yield components of the 2009 harvest.

Treatment	Grain Yield	Total Biomass	HI	Ears Plant^{-1}	Rows	Kernels Row^{-1}†
Sod application	(kg ha^{-1})	(kg ha^{-1})		no.	no.	no.
VE	10580 a	21979 a	0.48 a	0.98 a	17.1 a	30.1
V2	.	.	.	.	.	.
V4	11917 a	25148 a	0.47 a	0.97 a	17.5 a	34.9
V6	11615 a	24076 a	0.48 a	0.97 a	16.9 a	33.0
Control	11086 a	23312 a	0.48 a	0.96 a	17.4 a	32.8
Cultivar						
12	11546 a	23350 a	0.49 a	0.97 a	17.5 a	32.5
18	11052 a	23907 a	0.46 b	0.97 a	17.0 b	32.9

*Values followed by the same letter are not significant at the 0.05 probability level.
(.) Missing values.
†Interaction between sod treatment and cultivar.

Table 2. Yield and yield components of the 2010 harvest.

Treatment	Grain Yield	Total Biomass	HI	Ears Plant^{-1}	Rows	Kernels Row^{-1}
Sod application	(kg ha^{-1})	(kg ha^{-1})		no.	no.	no.
VE	11260 a	28454 a	0.40 a	0.98 a	18.4 a	38.0 a
V2	9880 a	25952 a	0.38 ab	1.00 a	18.2 a	38.5 a
V4	10702 a	29614 a	0.36 bc	1.10 a	17.9 a	38.2 a
V6	10819 a	29602 a	0.36 bc	1.00 a	17.9 a	37.2 a
Control	10180 a	28899 a	0.35 c	0.96 a	17.9 a	38.0 a
Corn Cultivar						
12	10357 a	28021 a	0.37 a	1.00 a	18.4 a	37.2 a
8	10780 a	28987 a	0.37 a	0.98 b	17.7 b	38.7 a

*Values followed by the same letter are not significant at the 0.05 probability level.
(.) Missing values.

Table 3. Height measurement, spad measuremeant, and leaf area index estimates over the 2009 growing season.

	Height Measurements (cm)					**Spad Measurements**					**Leaf Area Index**	
Treatment	**V6**	**V8**	**V12**	**V15**	**R1**	**V6**	**V8**	**V13**	**V18**	**R1**	**V8**	**R1**
Sod Application	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.
VE	51 a	86 a	154 a	211 a	257 b	48.5 b	50.5 b	49.0 b	42.3 b	50 b	1.73 a	3.95 c
V2	.	.	.	.	.	.	.	.	.	.	.	.
V4	49 a	87 a	161 a	217 a	261 ab	49.4 ab	52.3 a	52.2 a	47.6 a	53.8 a	1.96 a	4.20 bc
V6	52 a	91 a	165 a	222 a	270 a	51.2 a	53.3 a	52.0 a	46.1 a	56.4 a	2.06 a	4.57 ab
Control	52 a	87 a	163 a	218 a	266 ab	51.2 a	53.8 a	52.3 a	46.5 a	55.8 a	2.08 a	4.65 a
Corn Cultivar												
12	53 a	92 a	167 a	224 a	268 a	51 a	52.1 a	50.8 a	45.3 a	53.6 a	2.05 a	4.45 a
18	48 b	84 b	154 b	210 b	259 b	49.5 a	52.9 a	51.9 a	46.0 a	54.4 a	1.86 b	4.24 a

Values followed by the same letter are not significant at the 0.05 probability level.

Table 4. Height measurement and spad measuremeant over the 2010 growing season.

	Height Measurements (cm)			Spad Measurements
Treatment	**V6**	**V12**	**R1**	**V12**
Sod Application	no.	no.	no.	no.
VE	66 a	157 a	248 a	48.4 b
V2	62 a	146 a	235 b	48.1 b
V4	63 a	156 a	25 a	52.5 a
V6	60 a	152 a	249 a	50.4 b
Control	64 a	163 a	257 a	51.4 a
Corn Cultivar				
12	64 a	162 a	250 a	49.9 a
8	62 b	148 b	245 b	50.1 a

Values followed by the same letter are not significant at the 0.05 probability level.

CHAPTER 5: CONDUCTING A SUPERVISED ANALYSIS OF DIGITAL IMAGES USING R

A paper to be submitted to the Soil Science Society of America Journal

E. Scott Flynn, and Kenneth J. Moore

Abstract

Groundcover estimates are widely used in agronomic research when species performance or soil conservation is to be evaluated. Methods used to collect this type of data can be time consuming and labor intensive if collected using point analysis techniques. This not only increases time required to collect a data set but also can restrict the spatial scale over which data can be collected. Collecting data with digital cameras and separating cover classes with digital image analysis software can decrease time and labor required but the expense of software and the limited range of analysis available may be restrictive. Therefore, the authors suggest using digital images in conjunction with the free R statistical computing and graphics software package to perform digital image analysis. The objective of this article is to provide the basic code needed for conducting a digital image analysis in R. The code presented provides a basis to work with and analyze digital images but in no way should limit the user from customizing and expanding its capacities

Introduction

Groundcover estimates are widely used in agronomic research to quantify the effects of living plants and plant residues on crop production and soil conservation. Cover estimates have been used to assess residue management by tillage practices (Al-Kaisi and Hanna et. al., 2009), determine the erosion potential of crop land (Foster et.al., 2000), and to assess the relative competitiveness of weeds and perennial ground covers in row crops (Johnson et al., 1993; Flynn et al. 2011). Collecting cover data can be achieved by a variety of point analysis techniques that involve methods such as: in-field visual estimates based on the observer's perception of cover (Hanley,1978), in-field measurements with gridded quadrats (Laycock, 1980), or analysis of digital images with digital grids (Flynn et al. 2011). However, when one considers the time needed to collect and analyze these data sets and the error that can occur with multiple observers (Horst, 1984), then constraints on the robustness and spatial scale of data sets becomes apparent.

Digital image analysis with computer software has become an attractive solution to the issues associated with point analysis techniques (Richardson et al., 2001). Options such as batch processing of digital images, ease of use, and minimization of the user error allows for objectively collected, robust data sets to be obtained with minimal time and labor as compared to point analysis techniques. However, these techniques themselves have several constraining issues that prevent their use. First, software involved with digital image analysis can be expensive, especially if one works outside the domain of an organization's site licenses. Second, digital image analysis software can restrict the number of classification methods available for analysis due to the complexity and the number of statistical procedures possible.

To overcome these constraints on digital image analysis the authors suggest the use of the R statistical computing and graphics software package (R Development Core Team. 2009). R is a free software package in source code form that allows for an unlimited number of statistical procedures and allows the user to customize an analysis. Therefore the objective of this article is to provide the basic code needed for conducting a digital image analysis in R.

Software and Data Preparation

In order to use R for digital image analysis the user will need to download R from http://www.r-project.org/ and install and upload the following packages from the Packages option in the R toolbar:

ReadImages

DAAG

Depending on the type of analysis chosen, other packages may also need to be installed and upload to R. For example the package MASS will be needed if a linear or quadratic discriminate analysis is to be conducted.

Jpeg files may also require some preparation as digital cameras have the ability to collect high resolution images that can be difficult to process in R. Many photo editing software packages have the ability to resize images to reduce the number pixels contained within a photo. The R code presented here works well with images containing approximately 5×10^5 pixels but significant increases in analysis time will occur as the image size increases.

Use and Characteristics of Proposed R Code

The four basic tasks associated with conducting a supervised classification are: collection of a training data set, development of an appropriate classifier, classifying data of interest, and the output of information (Figure 1). Of these steps the creation of a training data set is one of the most critical points due to its importance in creating the classifier. For digital images the characteristics used to create the training data set is based on pixel color and the intensity of the three bands from which the color is derived (i.e. red, green, and blue bands (RGB)). The code in Figure 2 allows the user to choose a representative image and to interactively collect a training data set in R. This is accomplished by using the locator (loc) function to sample RGB values that correspond to the pixel class of interest. The result of this interactive sampling is a table of (x,y) locations, RGB values, and class estimates of each pixel sampled (Table 1). The authors have found the magnifier program installed on most PCs (start> programs> accessories> accessibility) works well in conjunction with R to allow the user to zoom in on an area of interest to collect class data.

Development of a classifier will need to be defined by the user as types and number of cover classes, quality of the photo, and the objectives of the user will determine the optimal classifier needed. The open programming language of R allows for a highly customizable analysis and an unlimited number of procedures to be applied and tested when seeking the correct classifier. For this reason when classifiers are specified in figures and codes they should be considered examples only.

Once a suitable classifier has been determined it can be applied to an image or group of images. The code presented in Figure 3 will randomly sample a user defined number of points within an image and apply the classifier to each sampled image located in the chosen working directory. By processing images in this manner, the time needed to analyze a single image can be greatly reduced while preventing the repetitive manual application of the classifier to other images of interest. Critical parameters that must be specified within this portion of the code are: the number of sample to be taken within the image, the number of classes used in the training data set, names of class, ground cover equations for each class, and the names given to those classes in the output data set. These critical points within the code are indicated with bold text.

After the analysis has been completed, three forms of output are saved in a .csv format in the working directory. These files are; the training data set (Table 1), and a table listing the analyzed images with their respective class breakdown (Table 2). A third output specifying the location, RGB values, and predicted class for each pixel classified is also created for each image. The form of this output is similar to that in Table 1 but sample identification numbers are also included in the output. Figure 4 gives an example of the use of this output for data presentation and validation. It should also be noted that by creating a .csv file with pixel classifications and their (x,y) locations, that data can also be download to into many other programs such as global information system (GIS) software for further data manipulation, analysis, and validation.

Conclusions

R can be used to customize an analysis to suit the objective of the user. The code presented here is just one example of how R can be used to perform a supervised classification of digital images and by no means is an ending point for conducting this procedure. The authors encourage users to further build on the presented code to suit their needs and to improve its capabilities and performance. By doing so the cost and time needed to collect such data sets will greatly decrease while increasing the scale of landscapes from which they can be collected.

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Tables

Table 1. Training data set created in R using the interactive method of data collection. If data is to be collected in a secondary program, then only RGB and class data are needed.

x	y	Red*	Green*	Blue*	Class
311	183	0.14902	0.286275	0.129412	vegetation
308	194	0.121569	0.121569	0.019608	vegetation
153	234	0.219608	0.290196	0.196078	vegetation
283	281	0.407843	0.345098	0.247059	soil
296	265	0.345098	0.243137	0.145098	soil
310	273	0.192157	0.14902	0.039216	soil

*RGB in R are scaled between 0 and 1in R from the traditional 0-255.

Table 2. Example ouptut of analyzed images with their respective breakdown of classes.

Class	Classified Image			
	101.JPG	102.JPG	103.JPG	104.JPG
	%	%	%	%
vegetation	90.81	88.31	77.01	10.62
soil	9.19	11.69	22.99	89.38

List of Figures

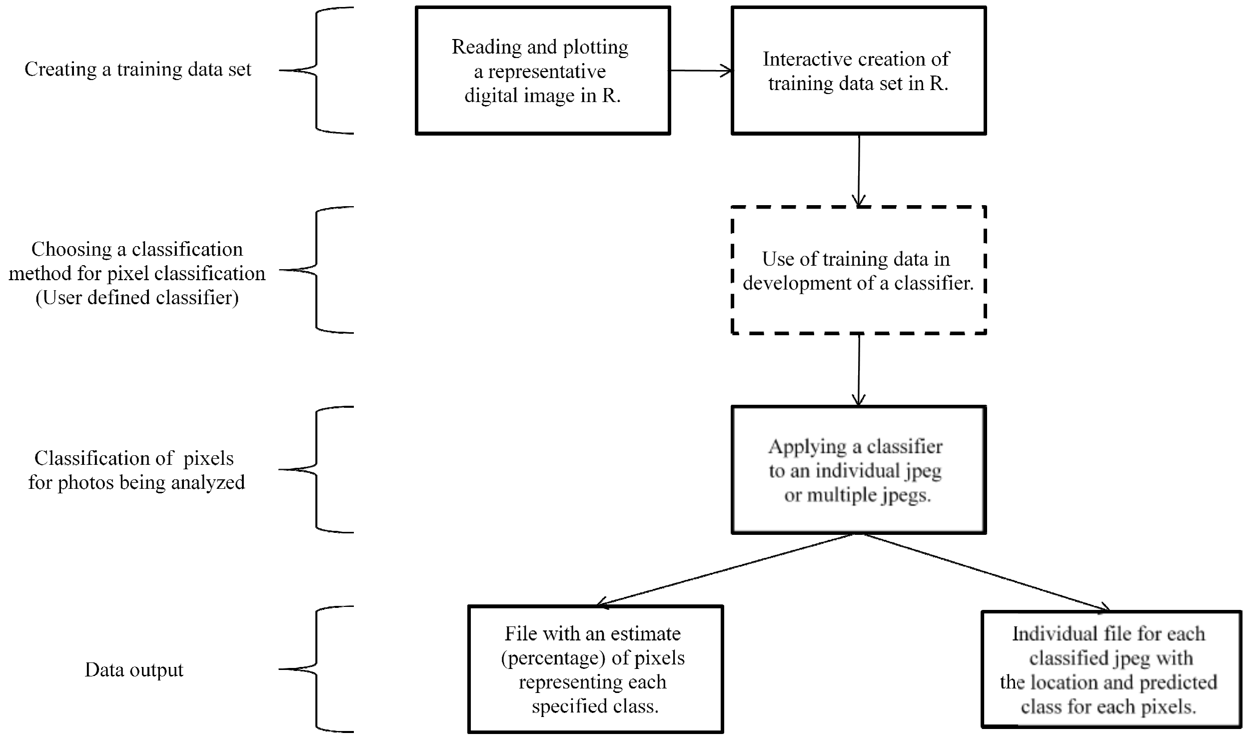

Figure 1. Workflow model of conducting a supervised classification in R. The dashed-bordered box is the location in the code that the user must define the type of classifier to be used when separating pixels into predetermined classes.

Step	R code	Function performed
1	setwd('**C:/Pictures**')	Creates a working directory within R. This working directory should be the folder in which your images of interest are located .
2	library(ReadImages) library(DAAG)	Loads the “ReadImages” and “DAAG” packages

3	get.class<-function(dat, npts, cls) {
	loc <- list(x=NULL,y=NULL)
	x <- NULL
	for(j in 1:length(cls)){
	print(paste("Click for ",cls[j]))
	pause()
	tmp <- locator(npts)
	loc$x <- c(loc$x,round(tmp$x,0))
	loc$y <- c(loc$y,round(tmp$y,0))
	for(i in 1:npts){
	x<-rbind(x,dat[loc$y
	[i+(j-1)*npts],loc$x[i+(j-
	1)*npts],]) }}
	data.classed<-data.frame(red=x[,1],green=x
	[,2],blue=x[,3],x=loc$x,y=
	loc$y,class=rep(cls,each=npts))
	return(data.classed)
	}
		Creation of a function called “get.class” that allows the user to interactively create a training data set from a digital image. The function collects data from the red, green, and blue (RGB) channels that are representative of the class being created. The function is requires three pieces of information:
		dat = image to be read
		npts = number of points to collect for each class
		cls = a vector of strings containing class names
		During use the code will pause and ask for the user to press <Enter> before proceeding to the next class to prevent mixing of class data. This is accomplished by clicking within the R console then pressing <Enter>.

	pic<-read.jpeg(file.choose()) plot(pic)	Reads and plots a jpeg image of the users choosing in a graphics window and names it “pic”. Once this function is initiated, a file choose window will open to allow the selection of an image from which the training data will be collected.
5	**training_data <- get.class(image, npts, c("class1", "class2", etc…))** example: training_data<-get.class(pic,10,c("vegetation","soil"))	This is an example of how to call and name the output of the “get.class” function created in step 1. “training_data” = user defined file name for T raining data. “image” = picture read in step 4. “npts” = number of points to be collected in each class. c(“ “,” “) = names the classes for which RGB data will be collected. *Note: There are no restrictions on the number of class that can be created.* During use the cursor will become cross shaped (+) so that user can center the cursor on the pixels of interest. Once the “npts” sample size has been reached the collection procedure will pause and ask for the user to press <Enter> before proceeding to the next class. This is accomplished by clicking within the R console then pressing <Enter>.

Bold text represents user defined parameters and options

Figure 2. R code for reading images and collecting a training data set for a supervised classifcation.

Step	R code	Function performed
7	**fit <- tree(class ~ red + green + blue,** **data=training_data)**	Example of a classifier created in R to be applied to images. In this case a linear discriminate analysis (lda) is conducted on the training data. *Note: Use of the lda function requires the "MASS" be installed.*

8	compute_cover<-function(data,afile){
	data2<-predict(fit,data,type=c("class"))
	data4<-as.data.frame(data3)
	names(data4)<-c("y","x","red","green","blue","class")
	
	vegetation<-((nrow(subset(data4,class=="vegetation",
	select=c(x,y,red,green,blue,class)))/nrow(data4))*100)
	soil<-((nrow(subset(data4,class=="soil",
	select=c(x,y,red,green,blue,class)))/nrow(data4))*100)
	returnlist<-list(**vegetation=vegetation, soil=soil**)
	write.csv(data4,file=paste(" ",gsub('.jpg',",afile,
	ignore.case=TRUE),".csv",sep=""))
	return(returnlist)
	}
		Creates a function that will apply the classifier in step 7 to all images within the working directory (step 1). Each image to be classified will be called "data" in the "compute_cover" function but once classified its will be renamed according to the image from which it was collected.
		
		In this example only two classes, vegetation and soil, are calculated. If more are specified in step 5 then this statement should be repeated for each additional class and named accordingly. Also these classes must be specified in the "list" function in order to be reported in the output that is created for each image.

9	alldata <- list.files(patt='.jpg', ignore.case=TRUE)
	final_output <- matrix(nrow=**2**)
	for (afile in alldata) {
	cat(paste("reading in file: ", afile, "\n"))
	x<-read.jpeg(afile)
	red<-x[,,1]
	green<-x[,,2]
	blue<-x[,,3]
	rows<-(1:nrow(red))
	columns<-(1:ncol(red))
	x<-sample(rows, **10000**, replace = TRUE)
	y<-sample(columns, **10000**,replace=TRUE)
	xy<-cbind(x,y)
	x1<-x*-1
	data<-cbind(x1,y,red[xy],green[xy],blue[xy])
	colnames(data)<-c("x","y","red","green","blue")
	data<-data.frame(data)
	cover <- compute_cover(data,afile)
	final_output <- cbind(final_output, cover)
	colnames(final_output)[ncol(final_output)] = afile
	}
		This portion of the code reads all ".jpg" or ".JPG" files that are present in the working directory (step 1). Two critical points within this section are the number of classes that will be created (line 2: nrow=) and the number of samples to be collected from each image (sample function lines 11 and 12). Rather than collecting data from each pixel, only samples are collected throughout the image allowing faster processing of images
		
		Note: Large images may slow analysis or be rejected by R. If this occurs, picture editing programs may be needed to resize the image. You can also reduce the image size (reduce pixel number) on most digital cameras before collecting images rather than editing in a secondary program.

10	write.csv(final_output, file="**cover_class.csv**") write.csv(**training_data,file="training_data.csv"**)	Creates two .csv files. The "cover_class" file is a summary data set in which all images classified are listed along with their respective class breakdown. The "training_data" file is the original training data created in step 1.

Bold text represents user defined parameters and options

Figure 3. R code for applying a classifier and creating output files of data sets created during the analysis.

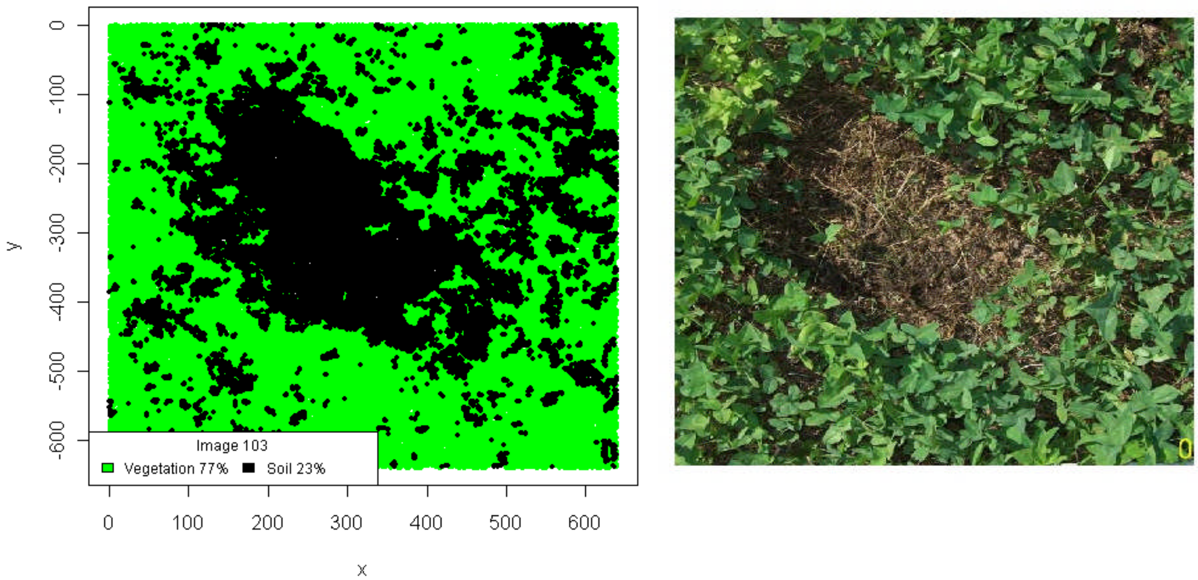

Figure 4. The plot on the left was derived using the location, and predicted pixel class from a classifier applied to the photo on the right. For this analysis only two classes were of interest; the green vegetation, and the bare soil.

CHAPTER 6: GENERAL CONCLUSION

Although much research has been conducted on corn and perennial ground cover production systems, the greatest achievements are likely to occur in the near future. Shifting the ideology from a resource limited system to a system that includes the plant's ability to perceive competition and alter growth in response will give future research more focus. The research and observations included in this document has lead to the belief that a successful corn in perennial ground cover production system can be created without the need for yearly application of herbicide.

The sensitivity of corn to early season competition is not only apparent within these studies but also in previous studies. This is a key factor in creating a successful perennial ground cover system and thus should be at the forefront of issues when considering species selection and management. It is possible that our ideotype for a perennial ground cover is incorrect as C3 species, which have optimum growth rate in the spring, are commonly used throughout this study area. Perhaps more focus should be placed on shade tolerant C4's or combinations of aggressive strip-tillage with aggressive spreading species.

Appendix I

Summary of notable studies concerning corn production in perennial ground covers

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM) ha^{-1}	Silage Yield (Mg DM ha^{-1})	Harvest index
Adams et al., 1970	Coastal bermudagrass	Lister planter; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Irrigation	-NA-	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	75 - 81	5.3 – 7.1	-NA-	-NA-
	Coastal bermudagrass	Strip-tillage (41 cm); 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Irrigation	-NA-	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	63 - 96	4.5 – 8.4	-NA-	-NA-
	Coastal bermudagrass	Chemical suppression; 211 kg ha^{-1} N (18 % applied at planting; 82 % at 50 cm corn ht.); Irrigation	Maleic Hydrazide 4.5	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	60	4.3 – 5.3	-NA-	-NA-
	Coastal bermudagrass	Chemical suppression; 211 kg ha^{-1} N (18 % applied at planting; 82 % at 50 cm corn ht.); Irrigation	Maleic Hydrazide 9.0	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	63 - 73	5.1 – 5.5	-NA-	-NA-
	Control (no vegetative cover)	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.);Irrigation**	**-NA-**	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);**	**100**	**7.0 – 8.7**	**-NA-**	**-NA-**
	tall fescue	Lister planter ; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Irrigation	-NA-	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Irrigation	95 – 96	8.7 – 9.2	-NA-	-NA-
	tall fescue	Chemical suppression ; 211 kg ha^{-1} N (18 % applied at planting ; 82 % at 50 cm corn ht.) ; Irrigation	Maleic Hydrazide 4.5	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Irrigation	72 – 91	6.9 – 8.3	-NA-	-NA-
	Control (no vegetative cover)	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Irrigation**	**-NA-**	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Irrigation**	**100**	**9.2 – 9.5**	**-NA-**	**-NA-**
	Coastal bermudagrass	Lister planter ; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Rainfed	-NA-	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	79 – 85	3.1 – 5.2	-NA-	-NA-
	Coastal bermudagrass	Strip-tillage (41 cm) ; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Rainfed	-NA-	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	67 - 85	3.1 - 4.4	-NA-	-NA-
	Coastal bermudagrass	Chemical suppression ; 211 kg ha^{-1} N (18 % applied at planting ; 82 % at 50 cm corn ht); Rainfed	Maleic Hydrazide 4.5	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	8 - 62	0.3 – 4.1	-NA-	-NA-
	Coastal bermudagrass	Chemical suppression ; 211 kg ha^{-1} N (18 % applied at planting ; 82 % at 50 cm corn ht); Rainfed	Maleic Hydrazide 9	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	15 - 72	0.6 – 4.8	-NA-	-NA-
	Control (no vegetative cover)	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Rainfed**	**-NA-**	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Rainfed**	**100**	**3.7 – 6.6**	**-NA-**	**-NA-**
	tall fescue	Lister planter ; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Rainfed		Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	82 - 89	3.8 – 5.8	-NA-	-NA-
	tall fescue	Chemical suppression ; 211 kg ha^{-1} N (18 % applied at planting ; 82 % at 50 cm corn ht);	Maleic Hydrazide 4.5	Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.);	13 - 22	0.6 – 1.4	-NA-	-NA-
	Control	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting ; 82% at 50 cm corn ht.); Rainfed**	-NA-	**Conventional Tillage; 211 kg ha^{-1} N (18 % applied at planting; 82% at 50 cm corn ht.); Rainfed**	**100**	4.6 – 6.6	-NA-	-NA-
Elkins et al., 1983	Tall fescue	No-till; No suppression; 224 kg ha^{-1} N; Hay removed before	-NA-	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	26	2.5	-NA-	-NA-

Appendix I

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Elkins et al., 1983	Tall fescue	No-till; Band suppression (0.23 m§); 224 kg ha^{-1} N; Hay removed before	Banded: Paraquat 0.8	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	50	4.9	-NA-	-NA-
	Tall fescue	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Maleic Hydrazide 6.7 Banded: Paraquat 0.8	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	51	5.0	-NA-	-NA-
	Tall fescue	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Glyphosate 1.7 + Atrazine 1.1 Banded: Paraquat 0.8	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	77	7.5	-NA-	-NA-
	Tall fescue	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Alachlor 3.4 + Atrazine 1.1 Banded: Paraquat 0.8	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	86	8.4	-NA-	-NA-
	Tall fescue	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Metolachlor 4.5 + Atrazine 1.1	Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	96	9.4	-NA-	-NA-
	Tall fescue (Control)	**No-till; Broadcast suppression; 224 kg ha^{-1} N; Hay removed before**	**Broadcast: Paraquat 0.6 + Atrazine 1.1**	**Tall fescue + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N**	**100**	**9.8**	-NA-	-NA-
	Orchardgrass	No-till; 224 kg ha^{-1} N; Hay removed before planting		Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	52	4.6	-NA-	-NA-
	Orchardgrass	No-till; Band suppression (0.23 m§); 224 kg ha^{-1} N; Hay removed before	Banded: Paraquat 0.8	Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	59	5.3	-NA-	-NA-
	Orchardgrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Atrazine 2.2 Banded: Paraquat 0.8	Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	103	9.2	-NA-	-NA-
	Orchardgrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Metolachlor 1.9 + Atrazine 1.5 Banded: Paraquat 0.8	Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	102	9.1	-NA-	-NA-
	Orchardgrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Metolachlor 3.4 + Atrazine 1.1 Banded: Paraquat 0.8	Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1+ 224 kg ha^{-1} N	90	8.1	-NA-	-NA-
	Orchardgrass	No-till; Broadcast suppression ; 224 kg ha^{-1} N; Hay removed before	Broadcast: Glyphosate 1.1 + Atrazine 1.1	Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	106	9.5	-NA-	-NA-
	Orchardgrass (Control)	**No-till; Broadcast suppression ; 224 kg ha^{-1} N; Hay removed before**	**Broadcast: Paraquat 0.6 + Atrazine 1.1**	**Orchardgrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N**	**100**	**8.9**	-NA-	-NA-
	Smooth Bromegrass	No-till; 224 kg ha^{-1} N; Hay removed before planting	-NA-	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	0 – 38	0 – 3.3	-NA-	-NA-
	Smooth Bromegrass	No-till; Band suppression (0.23 m§); 224 kg ha^{-1} N; Hay removed before	Banded: Paraquat 0.8	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.1 + 224 kg ha^{-1} N	2 – 36	0.2 – 2.6	-NA-	-NA-
	Smooth Bromegrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Atrazine 1.1 Banded: Paraquat 0.8	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N	85 – 89	7.3 – 7.6	-NA-	-NA-
	Smooth Bromegrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Atrazine 2.2 Banded: Paraquat 0.8	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N	101	8.7	-NA-	-NA-
	Smooth Bromegrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Metolachlor 1.9 + Atrazine 1.5 Banded: Paraquat 0.8	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N	82 – 96	7.0 – 8.2	-NA-	-NA-

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Elkins et al., 1983	Smooth Bromegrass	No-till; Broadcast and band suppression (0.23 m§);	Broadcast: Metolachlor 3.4 + Atrazine 1.1 Banded: Paraquat 0.8	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N	82 – 95	7.0 – 8.1	-NA-	-NA-
	Smooth Bromegrass	No-till; Broadcast suppression ; 224 kg ha^{-1} N; Hay removed before	Broadcast: Glyphosate 1.1 + Atrazine 1.1	Smooth bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N	98	8.4	-NA-	-NA-
	Smooth Bromegrass (Control)	**No-till; Broadcast suppression ; 224 kg ha^{-1} N; Hay removed before**	**Broadcast: Paraquat 0.6 + Atrazine 1.7**	**Smooth Bromegrass + Broadcast: Paraquat 0.6 + Atrazine 1.7 + 224 kg ha^{-1} N**	100	8.5 – 8.6	-NA-	-NA-
	Alfalfa	No suppression 140 kg ha^{-1} N; Hay removed before planting	-NA-	Alfalfa + Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2 + 140 kg ha^{-1} N	12	1.0	-NA-	-NA-
	Alfalfa	No-till; Broadcast suppression; 140 kg ha^{-1} N; Hay removed before	Broadcast: Propachlor 3.4 + Atrazine 2.2	Alfalfa + Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2 + 140 kg ha^{-1} N	78	6.7	-NA-	-NA-
	Alfalfa	No-till; Broadcast suppression; 140 kg ha^{-1} N; Hay removed before	Broadcast: Dicamba 0.6 + Propachlor 3.4 + Atrazine 2.2	Alfalfa + Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2 + 140 kg ha^{-1} N	95	8.2	-NA-	-NA-
	Alfalfa	No-till; Broadcast suppression; 140 kg ha^{-1} N; Hay removed before	Broadcast: Dicamba 0.6 + Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 1.1	Alfalfa + Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2 + 140 kg ha^{-1} N	92	8.0	-NA-	-NA-
	Alfalfa (Control)	**No-till; Broadcast suppression; 140 kg ha^{-1} N; Hay removed before**	**Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2**	**Alfalfa + Broadcast: Propachlor 3.4 + Atrazine 2.2 + 2, 4-D 2.2 + 140 kg ha^{-1} N**	**100**	**8.6**	-NA-	-NA-
Hall et al., 1984	Bird's-foot trefoil (cv "Dawn")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 4.5	Tilled (a)	47	3.2	-NA-	-NA-
	Bird's-foot trefoil (cv "Dawn")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 6.7	Tilled (a)	75	5.0	-NA-	-NA-
	Bird's-foot trefoil (cv "Dawn")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 2.2	Tilled (b)	71 - 73	5.0 – 5.1	-NA-	-NA-
	Bird's-foot trefoil (cv "Dawn")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 4.5	Tilled (b)	94 - 96	6.4 - 6.9	-NA-	-NA-
	Crownvetch (cv "Penngift")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 4.5	Tilled (b)	78 – 99	5.3 – 7.1	-NA-	-NA-
	Crownvetch (cv "Penngift")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 6.7	Tilled (a)	58	3.9	-NA-	-NA-
	Crownvetch (cv "Penngift")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 2.2	Tilled (b)	58 – 98	4.0 – 7.1	-NA-	-NA-
	Crownvetch (cv "Penngift")	Broadcast herbicide suppression; no-till	Paraquat 2.2 + Cyanazine 4.5	Tilled (a)	42	2.8	-NA-	-NA-
	Corn stover	No-till into corn stover	Paraquat 2.2 + Cyanazine 4.5	Tilled (a)	92	6.2	-NA-	-NA-
	Corn stover	No-till into corn stover	Paraquat 2.2 + Cyanazine 4.5	Tilled (b)	92 - 95	6.5 - 6.6	-NA-	-NA-

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Hall et al., 1984	Corn stover	No-till into corn stover	Paraquat 2.2 + Cyanazine 6.7	Tilled (a)	86	5.8	-NA-	-NA-
	Corn stover	No-till into corn stover	Paraquat 2.2 + Cyanazine 2.2	Tilled (b)	93 - 98	6.3 – 7.1	-NA-	-NA-
	Control a (no vegetative cover)	**Tilled a**	**Paraquat 2.2 + Cyanazine 4.5**	**Tilled (a)**	**100**	**6.7**	-NA-	-NA-
	Control b (no vegetative cover)	**Tilled b**	**Paraquat 2.2 + Cyanazine 2.2**	**Tilled (b)**	**100**	**6.8 - 7.2**	**-NA-**	**-NA-**
Scott et al., 1987	Medium red clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	100	6.2	-NA-	-NA-
	Mammoth red clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	103	6.4	-NA-	-NA-
	Alfalfa	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	98	6.0	-NA-	-NA-
	Yellow sweetclover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	100	6.1	-NA-	-NA-
	Bird's-foot trefoil	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	107	6.6	-NA-	-NA-
	Hairy vetch	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	104	6.4	-NA-	-NA-
	White clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	104	6.4	-NA-	-NA-
	Annual ryegrass	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	104	6.4	-NA-	-NA-
	Medium red clover + annual rygrass	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	102	6.3	-NA-	-NA-
	No vegetative cover	Banded herbicide suppression (0.2 m§); Conventional tillage;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 76 kg ha^{-1} N	62	3.8	-NA-	-NA-
	Control (no vegetative cover)	**Banded herbicide suppression (0.2 m§); Conventional tillage;**	Atrazine 1.1 + Alachlor 2.2	**Banded herbicide suppression (0.2 m§); Conventional tillage;**	**100**	6.5	-NA-	-NA-
	Medium red clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	62 – 96	3.0 – 3.9	-NA-	-NA-
	Mammoth red clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	53 – 70	2.8 – 3.5	-NA-	-NA-
	Alfalfa	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	50 – 77	2.7 – 3.1	-NA-	-NA-

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Scott et al., 1987	Yellow sweetclover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	50 – 87	2.7 – 3.4	-NA-	-NA-
	Bird's-foot trefoil	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	52 – 86	2.8 – 3.4	-NA-	-NA-
	Hairy vetch	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§) ; Conventional tillage; 95 kg ha^{-1} N	52 – 85	2.8 – 3.3	-NA-	-NA-
	White clover	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	49 – 89	2.6 – 3.5	-NA-	-NA-
	Annual ryegrass	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	39 – 62	1.9 – 2.8	-NA-	-NA-
	Medium red clover + annual rygrass	Banded herbicide suppression (0.2 m§); Seeded at 0.15 – 0.30 m corn height;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	53 – 91	2.6 – 3.8	-NA-	-NA-
	No vegetative cover	Banded herbicide suppression (0.2 m§); Conventional tillage;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	50 – 81	2.7 – 3.2	-NA-	-NA-
	No vegetative cover	Banded herbicide suppression (0.2 m§); Conventional tillage;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	69 – 100	3.3 – 3.9	-NA-	-NA-
	No vegetative cover	Banded herbicide suppression (0.2 m§); Conventional tillage;	Atrazine 1.1 + Alachlor 2.2	Banded herbicide suppression (0.2 m§); Conventional tillage; 95 kg ha^{-1} N	77 – 95	3.7 – 4.9	-NA-	-NA-
	Control (no vegetative cover)	**Banded herbicide suppression (0.2 m§); Conventional tillage;**	**Atrazine 1.1 + Alachlor 2.2**	**Banded herbicide suppression (0.2 m§); Conventional tillage;**	**100**	**3.9 – 5.4**	-NA-	-NA-
Enache and Ilnicki, 1990	Subterranean clover	No-till; 0 kg ha^{-1} N	-NA-	Conventional tillage; 0 kg ha^{-1} N	100 – 183	3.4* - 6.5	8.7 – 15.6	-NA-
	Rye (dead)	No-till; 0 kg ha^{-1} N	-NA-	Conventional tillage; 0 kg ha^{-1} N	18 – 47	.3 – 2.8	7.2 – 12.8	-NA-
	No ground cover	No-till; 0 kg ha^{-1} N	Atrazine 1.7 + Metolachlor 1.7	Conventional tillage; 0 kg ha^{-1} N	81 - 131	2.4 – 5.5	8.1 – 19.4	-NA-
	Subterranean clover	Disc tillage; 0 kg ha^{-1} N	-NA-	Conventional tillage; 0 kg ha^{-1} N	82 - 175	3.3 – 5.8	8.2 – 19.2	-NA-
	Rye (dead)	Disc tillage; 0 kg ha^{-1} N	-NA-	Conventional tillage; 0 kg ha^{-1} N	31 - 85	.6 – 5.1	7.2 – 12.8	-NA-
	No ground cover	Disc tillage; 0 kg ha^{-1} N	Atrazine 1.7 + Metolachlor 1.7	Conventional tillage; 0 kg ha^{-1} N	66 – 94	1.4 – 5.7	7.4- 16.4	-NA-
	Subterranean Clover	Conventional tillage; 0 kg ha^{-1} N	-NA-	C Conventional tillage; 0 kg ha^{-1} N	77 - 156	2.9 – 6.7	9.1 – 13.9	-NA-
	Rye (dead)	Conventional tillage; 0 kg ha^{-1} N	-NA-	Conventional tillage; 0 kg ha^{-1} N	8 - 80	0.1 – 4.8	6.7 – 14.6	-NA-

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Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Enache and Ilnicki, 1990	**Control (no vegetative cover)**	**Conventional tillage; 0 kg ha^{-1} N**	**Atrazine 1.7 + Metolachlor 1.7**	**Conventional tillage; 0 kg ha^{-1} N**	**100**	**1.9 – 6.3**	**6.2 – 14.7**	-NA-
Eberlein et al., 1992	Alfalfa (cv "Pioneer 532")	No suppression ; Irrigation; 146 – 160 kg ha^{-1} N	-NA-	Tillage ; irrigation; 146 – 160 kg ha^{-1} N	17 - 37	1.5 - 3.3	-NA-	0.44 - 0.48‡
	Alfalfa (cv "Pioneer 532")	Broadcast herbicide suppression; Irrigation; 146 – 160 kg ha^{-1} N	Atrazine 1.7 + COC¶ 2.8 L ha^{-1}	Tillage ; irrigation; 146 – 160 kg ha^{-1} N	95 - 102	8.3 - 9.0	-NA-	0.52‡
	Alfalfa (cv "Pioneer 532")	Banded herbicide suppression (0.38 m§) ; Irrigation; 146 – 160 kg ha^{-1} N	Atrazine 3.4 + COC¶ 2.8 L ha^{-1}	Tillage ; irrigation; 146 – 160 kg ha^{-1} N	93 - 99	8.7 - 8.2	-NA-	0.51 – 0.53‡
	Alfalfa (cv "Pioneer 532")	Sod-kill ; no-till ; Irrigation; 146 – 160 kg ha^{-1} N	Atrazine 1.7 + Glyphosate 1.7 + COC¶ 2.8 L ha^{-1}	Tillage ; irrigation; 146 – 160 kg ha^{-1} N	97 - 100	8.8 - 8.6	-NA-	0.49 - 0.50 ‡
	Control	**Tillage ; Irrigation; 146 – 160 kg ha^{-1} N**	-NA-	**Tillage ; irrigation; 146 – 160 kg ha^{-1} N**	**100**	**8.8 - 8.8**	-NA-	**0.50 – 0.51‡**
	Alfalfa (cv "Pioneer 532")	No suppression ; rainfed; 146 – 160 kg ha^{-1} N	-NA-	Tilled ; rainfed; 146 - 160 kg ha^{-1} N	1 - 4	0.1 - 0.4	-NA-	0.06 – 0.19‡
	Alfalfa (cv "Pioneer 532")	Broadcast herbicide suppression ; rainfed; 146 – 160 kg ha^{-1} N	Atrazine 1.7 + COC¶ 2.8 L ha^{-1}	Tilled ; rainfed; 146 - 160 kg ha^{-1} N	62 - 91	5.6 - 7.5	-NA-	0.50 - 0.52‡
	Alfalfa (cv "Pioneer 532")	Banded herbicide suppression (0.38 m§); rainfed ; 146 – 160 kg ha^{-1} N	Atrazine 3.4 + COC¶ 2.8 L ha^{-1}	Tilled ; rainfed; 146 - 160 kg ha^{-1} N	45 - 54	4.5 - 4.1	-NA-	0.40 - 0.50 ‡
	Alfalfa (cv "Pioneer 532")	Sod-kill ; no-till ; rainfed ; 146 – 160 kg ha^{-1} N	Glyphosate 1.7 + Atrazine 1.7 + COC¶ 2.8 L ha^{-1}	Tilled ; rainfed; 146 - 160 kg ha^{-1} N	95 - 97	8.8 - 7.9	-NA-	0.51 - 0.55‡
	Control (no vegetative cover)	**Tilled ; rainfed; 146 - 160 kg ha^{-1} N**	-NA-	**Tilled ; rainfed; 146 - 160 kg ha^{-1} N**	**100**	**8.2 - 9.1**	-NA-	**0.49 – 0.54‡**
Martin et al., 1999	White clover/grass mix	Strip-tillage (0.30 m§); 115 kg ha^{-1} N	-NA-	Tilled; 115 kg ha^{-1} N	23 - 55	-NA-	2.7* - 5.7*	0.25 - 0.31
	White clover/grass mix	Herbicide suppression (0.30 m§); 115 kg ha^{-1} N	Atrazine 1.5 + Glyphosate 1.1	Tilled; 115 kg ha^{-1} N	52 - 61	-NA-	6.0 *- 6.4*	0.28 - 0.32
	White clover/grass mix	Strip-till; herbicide suppression (0.30 m§); 115 kg ha^{-1} N	Atrazine 1.5 + Glyphosate 1.1	Tilled; 115 kg ha^{-1} N	59 - 77	-NA-	6.8* - 8.0	0.31 - 0.35
	no vegetative cover	Tilled; 115 kg ha^{-1} N	**Atrazine 1.5 + Glyphosate 1.1**	Tilled; 115 kg ha^{-1} N	60 - 66	-NA-	4.0 - 6.0	0.32 – 0.32
	Control	**Tilled; 115 kg ha^{-1} N**	**Atrazine 1.5 + Glyphosate 1.1**	**Tilled; 115 kg ha^{-1} N**	**100**	-NA-	**10.4 - 11.6**	**0.30 - 0.35**
Abdin et al., 2000	Hairy vetch	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	80 - 103	7.0*-9.0	-NA-	-NA-

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Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Abdin et al., 2000	Fall rye (cv "Prima")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	86 - 101	7.5*- 8.8	-NA-	-NA-
	Red clover + ryegrass (cv's "Khun" + "Marshall")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	83 - 107	7.2* - 9.3	-NA-	-NA-
	White clover + ryegrass (cv's "Ladino" + "Marshall")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	86 - 101	7.5*- 8.8	-NA-	-NA-
	Subterranean clover (cv "Northam")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	72 - 102	6.3* - 8.9	-NA-	-NA-
	Yellow sweet clover	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	86 - 100	7.5* - 8.7	-NA-	-NA-
	Black medic	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	81 - 98	7.1* - 8.5	-NA-	-NA-
	Persian clover	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	77 - 99	6.7* - 8.6	-NA-	-NA-
	Strawberry clover (cv "Salina")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	78 - 102	6.8* - 8.9	-NA-	-NA-
	Crimson clover	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	74 - 111	6.4* - 9.7	-NA-	-NA-
	Alfalfa (cv "Nitro")	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	79 - 101	6.9* - 8.8	-NA-	-NA-
	Berseem clover	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	87 - 108	7.6* - 9.4	-NA-	-NA-
	Hand weeded (no vegetative cover)	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	99 – 103	8.6 - 9.0	-NA-	-NA-
	Weedy	Seeded 10 – 20 DAE; 180 kg ha^{-1} N	-NA-	Herbicide weed control; 180 kg ha^{-1} N;	62 - 80	5.4 – 7.0	-NA-	-NA-
	Control (no vegetative cover)	**Herbicide weed control; 180 kg ha^{-1} N;**	**Atrazine 1.0 + Metolachlor 1.9**	**Herbicide weed control; 180 kg ha^{-1} N;**	**100**	**8.7**	**-NA-**	**-NA-**
Zemenchik et al., 2000	Kura clover (cv. "Rhizo")	Sod-kill; 45 kg ha^{-1} N (no-till)	Glyphosate 3.4	No-till; sod-kill	102	9.4	-NA-	0.57‡
	Kura clover (cv. "Rhizo")	No-till; band-kill (0.61 m§)	Glyphosate 4.0	No-till; sod-kill	85 - 87	7.6 - 7.9	-NA-	0.57‡
	Kura clover (cv. "Rhizo")	No-till; broadcast herbicide suppression; 45 kg ha^{-1} N	Glyphosate 1.7	No-till; sod-kill	70 - 99	6.4 - 8.7	-NA-	0.53 - 0.61‡
	Kura clover (cv. "Rhizo")	No-till; broadcast herbicide suppression	Glyphosate 4.0	No-till; sod-kill	66 - 83	6.1 - 7.3	-NA-	0.47 - 0.55‡

Author	Ground Cover	Management	Cover suppression (kg/ha, unless otherwise specified)	Control†	Relative to control† (%)	Grain Yield (Mg DM ha^{-1})	Silage Yield (Mg DM ha^{-1})	Harvest index
Zemenchik et al., 2000	**Control (no vegetative cover)**	**No-till; sod-kill**	**Glyphosate 3.4**	**No-till; sod-kill**	**100**	**8.8 - 9.2**	-NA-	**0.52 – 0.64‡**
Liedgen et al., 2004a	Italian ryegrass (cv “Lipo”)	Hand strip-tillage (0.30 m) ; Broadcast herbicide suppression ;110 kg ha-1 N (45 % applied at planting ; 55 % at	Primafit A® 9 l ha^{-1} (19% Metolachlor, 9.5% Atrazine, and 9.5%	Hand tillage Broadcast; herbicide suppression; 110 kg ha^{-1} N (45 % applied at planting ; 55 **% at V2)**	28 – 86%	2.2 – 5.6	-NA-	0.34 – 0.63
	Control (no vegetative cover)	**Hand tillage Broadcast; herbicide suppression; 110 kg ha^{-1} N (45 % applied at planting ; 55 % at V2)**	**Primafit A® 9 l ha^{-1} (19% Metolachlor, 9.5% Atrazine, and 9.5%**	**Hand tillage Broadcast; herbicide suppression; 110 kg ha^{-1} N (45 % applied at planting ; 55 % at V2)**	**100**	6.6 - 10	-NA-	**0.36 – 0.59**

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production. Type III test of fixed effects for yield, yield yield components, and height measurements.

	Grain Yields	**Total Biomass†**	**Harvest Index†**	**Population**	**Ear/Plant**	**Grain/Cob**	**Mature Corn Height**	**Mature Cover Height**
Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Position	0.9834	0.9743	0.6784	0.0021	0.9422	0.7771	0.8035	**0.0010**
Species	**<.0001**	**<.0001**	**0.0004**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	**<.0001**
Year	**0.0066**	0.0551	0.4951	**<.0001**	**0.0065**	**0.0462**	0.8377	**0.0370**
Position x Species	0.0912	**0.0091**	0.4212	0.5097	0.7162	0.5201	**0.0037**	**0.0126**
Position x Year	0.6458	0.4454	0.1363	0.2091	0.6572	0.5865	0.6720	0.6840
Species x Year	**<.0001**	**<.0001**	0.1371	**0.0003**	**0.0001**	**0.0014**	**<.0001**	**<.0001**
Position x Species x Year	**0.0013**	**0.0325**	0.0761	0.2460	0.3100	0.1018	0.9346	**0.0408**

Bold values are significant at 0.05 level

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production. Type III test of fixed effects for spring and fall ground cover.

	Spring Cover	**Total Fall Cover**			**Strip-tillage Zone Cover**			**Inter-row Cover**		
	Species Cover	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil
Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Position	**0.0319**	0.9169	0.7721	0.3142	0.9276	0.7351	0.2774	0.9104	0.7904	0.4058
Species	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Year	0.1278	0.5617	0.6612	0.4216	0.8548	0.3403	0.5216	0.2683	0.6405	0.3248
Position x Species	0.1110	0.1847	0.2411	0.0774	**0.0388**	0.1449	0.6566	0.6491	0.5411	**0.0371**
Position x Year	0.0846	0.4364	0.4061	0.7850	0.3559	0.3366	0.7294	0.4397	0.3566	0.8824
Species x Year	**0.0025**	0.4029	**0.0470**	0.9999	0.3630	0.1155	0.9673	0.2439	**0.0351**	0.847
Position x Species x Year	0.1261	0.4051	0.7028	0.2636	0.4407	0.7585	0.3040	0.2497	0.3297	0.5913

Bold values are significant at 0.05 level

Appendix III

Appendix IV

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production. Type III test of fixed effects for yield, yield yield components for individual years.

		Grain Yields	Total Biomass†	Harvest Index†	Population	Ear/Plant	Grain/Cob
Year	Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
2008	Position	0.9264	0.9373	0.6462	0.0732	0.8860	-
	Species	**<.0001**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	-
	Position x Species	0.1873	0.0633	0.9963	0.4497	0.9984	-
2009	Position	0.8087	0.8573	0.3259	0.6003	0.7338	0.4060
	Species	**<.0001**	**<.0001**	**0.0002**	**0.0001**	**<.0001**	**0.0004**
	Position x Species	**0.0037**	**0.0013**	0.1638	0.0550	0.4057	0.2187
2010	Position	0.6664	0.5796	0.6746	0.0524	0.7223	0.4261
	Species	**<.0001**	**<.0001**	**0.0023**	**0.0028**	**0.0039**	**0.0003**
	Position x Species	0.2634	0.2189	0.3966	0.242	0.3893	0.4834

Bold values are significant at 0.05 level

Appendix V

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production. Type III test of fixed effects for spring and fall cover for individual years.

		Spring Cover	**Total Fall Cover**			**Strip-tillage Zone Cover**			**Inter-row Cover**		
		Species Cover	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil	Species Cover	Corn Residue	Bare Soil
Year	Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
2008	Position	0.4021	-	-	-	-	-	-	-	-	-
	Species	**<.0002**	-	-	-	-	-	-	-	-	-
	Position x Species	0.1009	-	-	-	-	-	-	-	-	-
2009	Position	**0.0087**	0.3930	0.7471	0.3927	0.4133	0.9714	0.3749	0.4102	0.4616	0.424
	Species	**<.0001**	**<.0001**	**0.0009**	**<.0001**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	**0.0162**	**0.0002**
	Position x Species	0.0133	0.5873	0.6727	0.5910	0.0963	0.6888	0.7114	0.4582	0.7087	0.5245
2010	Position	0.0185	0.8576	0.6391	0.2483	0.7512	0.5581	0.2381	0.9231	0.7165	0.5104
	Species	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0003**	**<.0001**	**<.0001**	**0.0002**	**<.0001**
	Position x Species	0.4857	0.2583	0.1592	0.0145	0.1454	0.1031	0.2955	0.7059	0.3861	0.0320

Bold values are significant at 0.05 level

Appendix VI

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production. Type III test of fixed effects for corn and perennial ground cover heights.

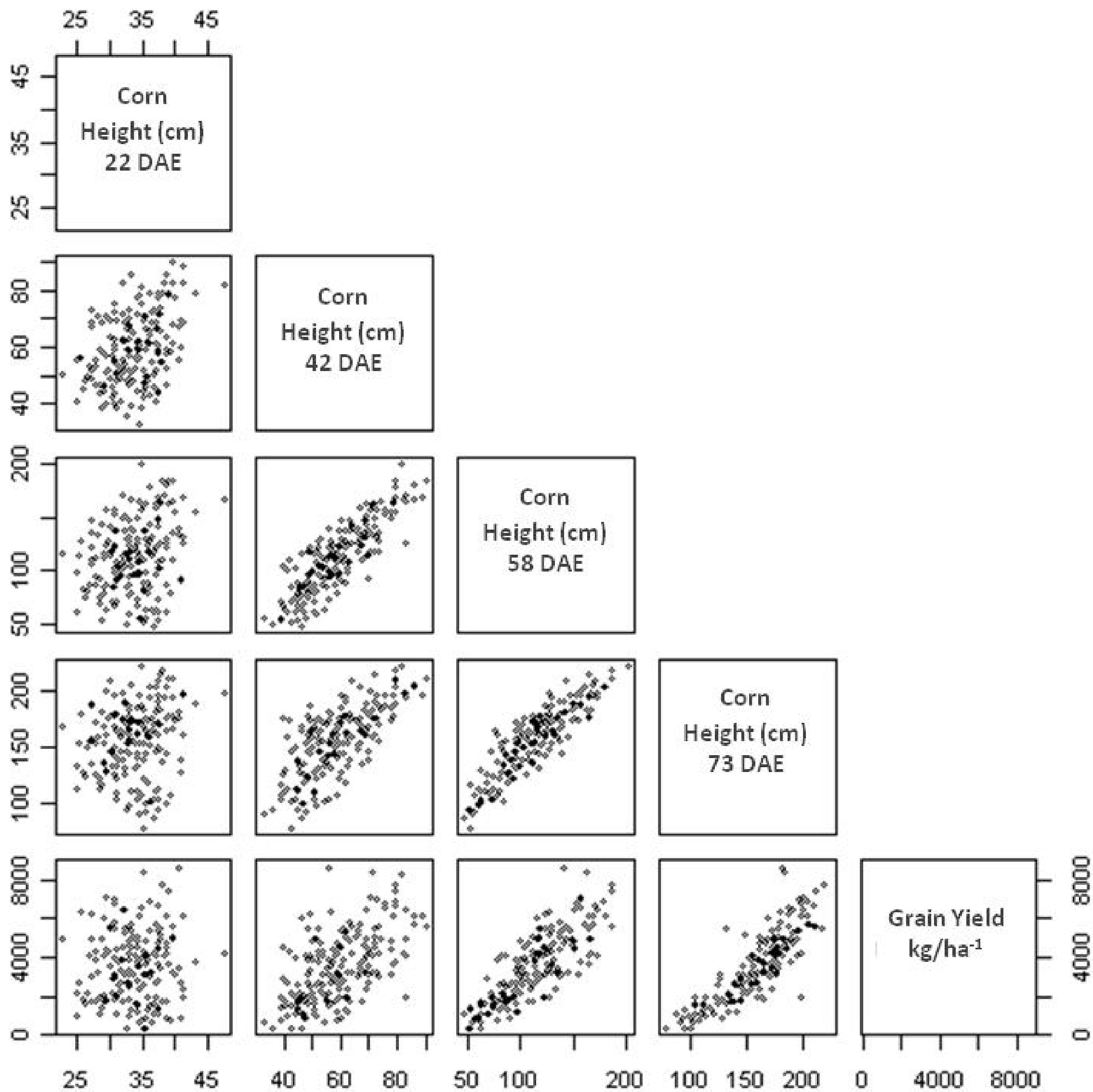
year	Effect	Corn Height					Ground Cover Height at Maturity
		22 DAE	42 DAE	58 DAE	73 DAE		42 DAE
		Pr > F	Pr > F	Pr > F	Pr > F	-	Pr > F
2008	Position	0.0281	0.6084	0.9199	0.8241	-	0.0568
	Species	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**-**	**<.0001**
	Position x Species	0.6811	0.1865	0.1526	0.0778	-	0.8170
		33 DAE	41 DAE	53 DAE	63 DAE	76 DAE	33 DAE
2009	Position	0.0739	0.5743	0.7371	0.8542	0.8222	0.0777
	Species	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
	Position x Species	0.5543	0.1042	0.0507	0.3572	0.5437	0.0630
		42 DAE	57 DAE	71 DAE	88 DAE	-	57 DAE
2010	Position	0.3946	0.1075	0.6914	0.7973	-	0.1075
	Species	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**-**	**0.0001**
	Position x Species	0.8302	0.0667	**0.0440**	0.3041	-	0.0667

Means followed by the same letter are not significant at the 0.05 level
DAE (days after emergence)

Appendix VII

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production.

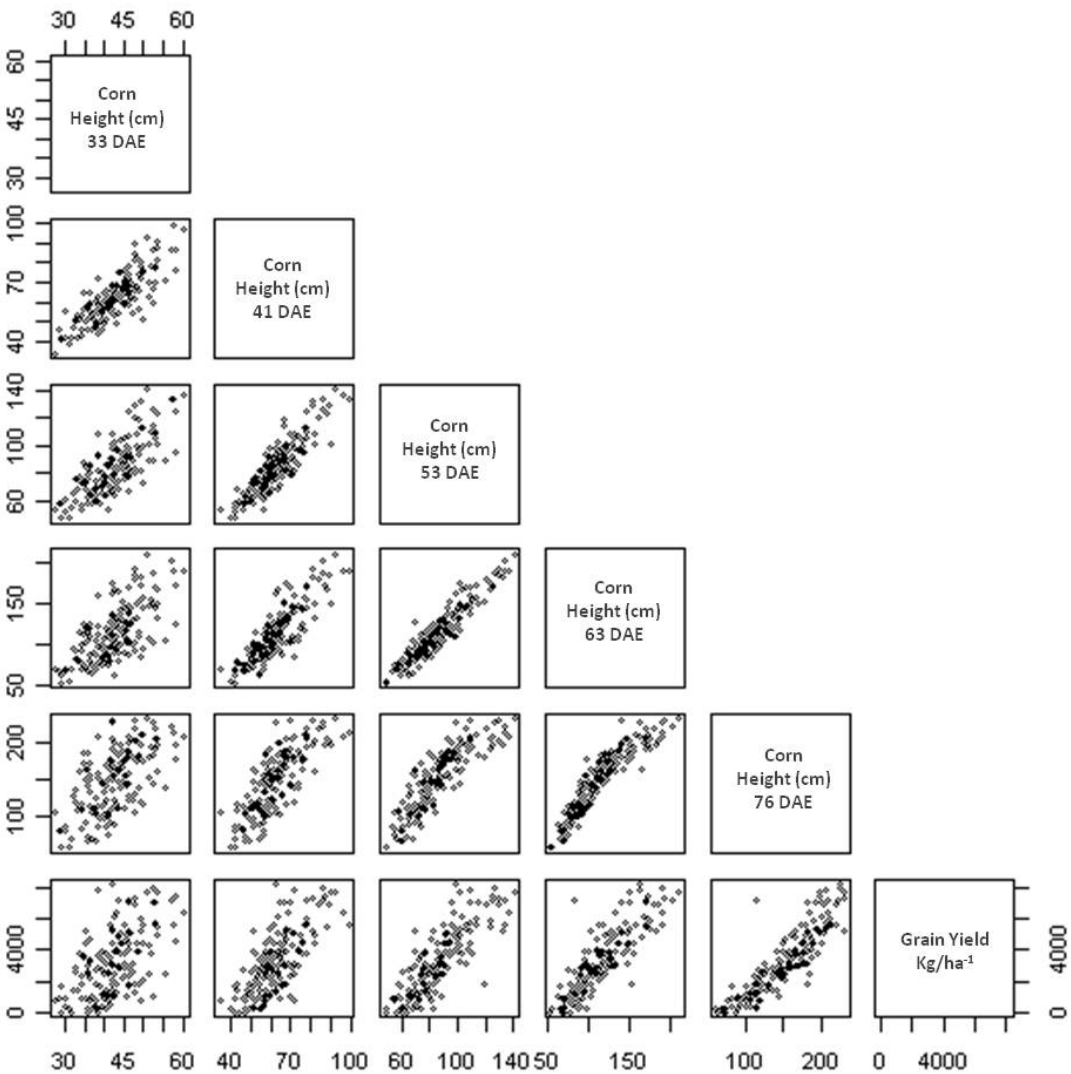
Correlation Matrix for corn height at sampling dates and final gain yield in 2008.



Appendix VIII

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production.

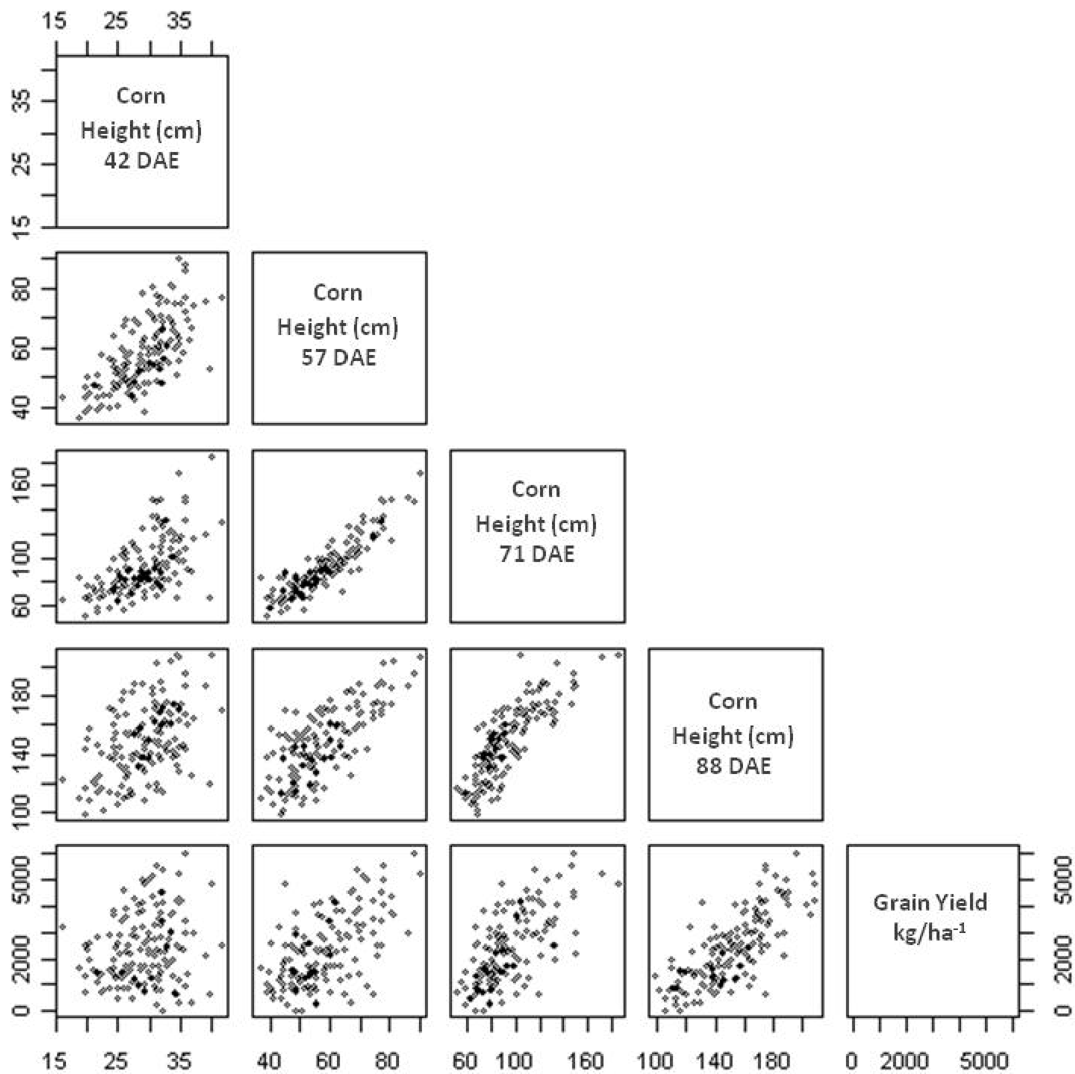
Correlation Matrix for corn height at sampling dates and final gain yield in 2009.



Appendix IX

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production.

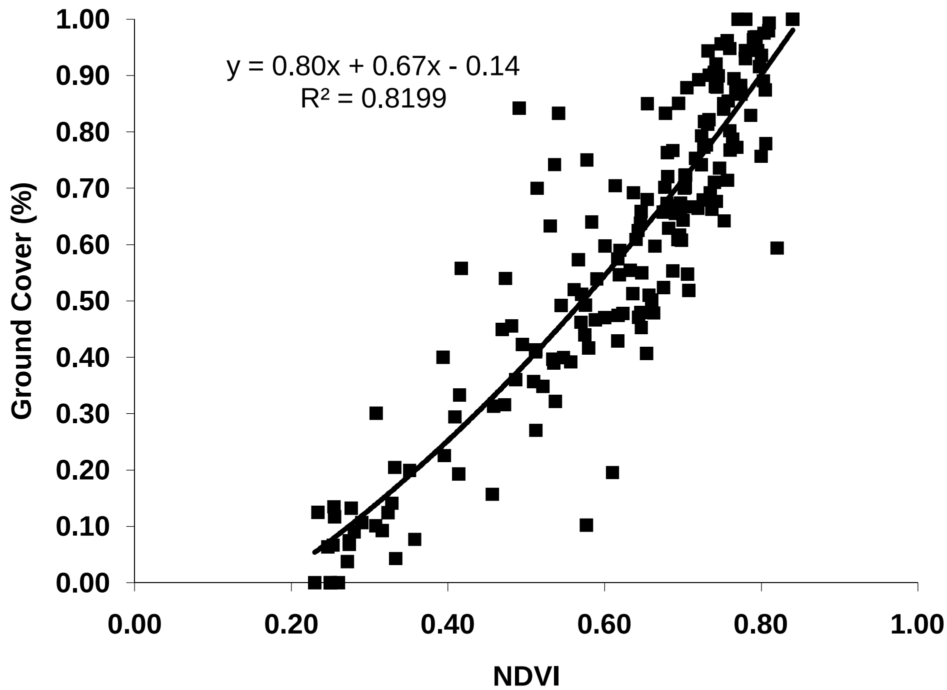
Correlation matrix for corn height at sampling dates and final gain yield in 2010.



Appendix X

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production.

Calibration of NDVI for estimating ground cover using digital point analysis of photos.



Appendix XI

Red/Far-Red Effect on Corn Growth and Development in Perennial Ground Covers. Type III test of fixed effects for yield and yield components of the 2009 harvest.

	Grain Yield	Total Biomass	HI	Ears Plant^{-1}	Rows	Columns
Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Sod	0.3346	0.1640	0.8729	0.7003	0.4525	**0.0012**
Cultivar	0.3683	0.5742	**<.0001**	0.9523	**0.0416**	0.6322
Sod xCultivar	0.3105	0.1112	0.3849	0.6888	0.8988	**0.0154**

Bold values are significant at the 0.05 level.

Appendix XII

Red/Far-Red Effect on Corn Growth and Development in Perennial Ground Covers. Type III test of fixed effects for yield and yield components of the 2010 harvest.

	Grain Yield	Total Biomass	HI	Ears Plant^{-1}	Rows	Columns
Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Sod	0.4156	0.4134	**0.0180**	0.1766	0.3450	0.8314
Cultivar	0.3877	0.4694	0.6925	**0.0476**	**0.0015**	0.0530
Sod xCultivar	0.3701	0.3443	0.8356	0.5489	0.9136	0.8811

Bold values are significant at the 0.05 level.

Appendix XIII

Red/Far-Red Effect on Corn Growth and Development in Perennial Ground Covers. Type III test of fixed effects for plant and canopy measurements in 2009.

	Height Measurements					**Spad Measurements**					**Leaf Area Index**	
	V6	V8	V12	V15	R1	V6	V8	V13	V18	R1	V8	R1
Effect	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Sod	0.6269	0.5857	0.1282	0.1005	**0.0470**	**0.0199**	**0.0007**	**0.0069**	**0.0004**	**0.0003**	0.1271	**0.0177**
Cultivar	**0.0098**	**0.0006**	**0.0005**	**0.0002**	**0.0100**	0.0822	0.1196	0.0921	0.3920	0.3747	**0.0369**	0.0770
Sod xCultivar	0.0622	0.4895	0.3407	0.3985	0.8266	0.8234	0.4302	0.1502	0.3740	0.7781	0.7659	0.4306

Bold values are significant at the 0.05 level.

Appendix XIV

Red/Far-Red Effect on Corn Growth and Development in Perennial Ground Covers. Type III test of fixed effects for plant and canopy measurements in 2010.

	Height Measurements			Spad Measurements
	V6	V12	R1	V12
Effect	Pr > F	Pr > F	Pr > F	Pr > F
Sod	0.1395	0.0738	**0.0058**	**0.0037**
Cultivar	**0.0321**	**<.0001**	**0.0127**	0.5665
Sod xCultivar	0.0943	0.4233	0.0725	0.6760

Bold values are significant at the 0.05 level.

Appendix XV

Example of batch digital image analysis in R.

```
setwd('C:/Pictures')

fit <- lda(class ~ red + green + blue,   data=training_data)
        print(fit) # view results
        plot(fit)


compute_cover<-function(data,afile){

        data2<-predict(fit,data,type=c("class"))
        data3<-cbind(data,data2)
        data4<-as.data.frame(data3[c(1:6)])
        names(data4)<-c("y","x","red","green","blue","class")
        vegetation<-((nrow(subset(data4,class=="vegetation",
                  select=c(x,y,red,green,blue,class)))/nrow(data4))*100)
        soil<-((nrow(subset(data4,class=="soil",
                  select=c(x,y,red,green,blue,class)))/nrow(data4))*100)

        returnlist<-list(vegetation=vegetation,soil=soil)

        write.csv(data4,file=paste("",gsub('.jpg','',afile,ignore.case =
                TRUE),".csv",sep=""))
        return(returnlist)
}

alldata <- list.files(patt='.jpg', ignore.case=TRUE)

final_output <-  matrix(nrow=2)
for (afile in alldata) {
cat(paste("reading in file: ", afile, "\n"))
        x<-read.jpeg(afile)
        red<-x[,,1]
        green<-x[,,2]
        blue<-x[,,3]

        rows<-(1:nrow(red))
        columns<-(1:ncol(red))
        x<-sample(rows, 10000, replace = TRUE)
        y<-sample(columns, 10000,replace=TRUE)
        xy<-cbind(x,y)
        x1<-x*-1

        data<-cbind(x1,y,red[xy],green[xy],blue[xy])
        colnames(data)<-c("x","y","red","green","blue")
        data<-data.frame(data)
        cover <- compute_cover(data,afile)
        final_output <- cbind(final_output, cover)
        colnames(final_output)[ncol(final_output)] = afile
}

write.csv(final_output, file="cover_class.csv")

write.csv(training_data,file="training_data.csv")
```

Appendix XVI

Example of single photo digital image analysis in R.

```
setwd('C:/Pictures')

fit <- lda(class ~ red + green + blue,   data=training_data)
        print(fit) # view results
        plot(fit)


x<-read.jpeg(file.choose())
red<-x[,,1]
green<-x[,,2]
blue<-x[,,3]

rows<-(1:nrow(red))
columns<-(1:ncol(red))
x<-sample(rows, 100000, replace = TRUE)
y<-sample(columns, 100000,replace=TRUE)
xy<-cbind(x,y)
x1<-x*-1

data<-cbind(x1,y,red[xy],green[xy],blue[xy])
        colnames(data)<-c("x","y","red","green","blue")
        data<-data.frame(data)
        data2<-predict(fit,data)
        data3<-cbind(data,data2)
        data4<-as.data.frame(data3)
        names(data4)<-c("y","x","red", "green", "blue","class")
        vegetation<-((nrow(subset(data4,class=="vegetation",
                select=c(x,y,red,green,blue,class)))/nrow(data4))*100)
        soil<-((nrow(subset(data4,class=="soil",
                select=c(x,y,red,green,blue,class)))/nrow(data4))*100)

        returnlist<-list(vegetation=vegetation,soil=soil)
        returnlist



write.csv(data4,file = "pic.csv")
```